SPECTRUM ANALYSIS

IN ITS APPLICATION TO

TERRESTRIAL SUBSTANCES,

AND

THE PHYSICAL CONSTITUTION OF THE HEAVENLY BODIES.

FAMILIARLY EXPLAINED BY THE LATE

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AND

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TRANSLATORS' PREFACE.

THE rapid advance of Spectrum Analysis as a method of scientific inquiry has rendered the publication of new works on the subject a frequent necessity.

This was so evident to the late Dr. Schellen, that when a third edition of his valuable book was called for, he set himself the task of reconstructing the whole work, as in no other way could the mass of new material he had accumulated be fittingly introduced. While thus engaged he was attacked by the lingering illness to which unhappily he has recently succumbed, and which obliged him, for the satisfactory completion of his labours, to seek a coadjutor in his esteemed friend Dr. H. J. Klein.

In preparing the work for English readers the translators have been favoured by the valuable counsel of the Editor, Captain Abney, by whom the whole has been revised and somewhat remodelled. The additional new matter introduced

by the Editor to bring up the work as near to date as possible is distinguished throughout by its insertion within brackets. The Editorial Notes by Dr. Huggins to the former English Edition now form part of the text into which they have been incorporated by Dr. Schellen.

By the excision of all unnecessary or obsolete portions, the Editor has been able so far to compress the original work as to bring it within the limits of one volume.

JANE AND CAROLINE LASSELL.

RAY LODGE, MAIDENHEAD,
May, 1885.

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PART FIRST.

ON THE ARTIFICIAL SOURCES OF HIGH DEGREES OF HEAT AND LIGHT.

ON THE ARTIFICIAL SOURCES OF HIGH DEGREES OF HEAT AND LIGHT.

1. Introduction.

Light, whether emitted from the heavenly bodies or from any artificial source, presents no difference to the unassisted eye beyond a variation in colour and brilliancy. But when subjected to the action of a prism, by which it is separated into its component colours in the formation of a *spectrum*, great differences become apparent, and these differences depend so entirely upon the source of light as to afford a sure index of its nature. The aspect of a spectrum is so fully characteristic that to every substance when rendered luminous, either in a state of incandescence or as luminous gas or vapour, there corresponds at a given temperature a special and peculiar spectrum.

It follows, therefore, that when the spectra of different substances have been determined and recorded, it is easy to recognise, from the form of the spectrum which a body of unknown constitution presents, the individual substances of which such a body is composed.

This statement presents in general terms the nature of spectrum analysis. It analyses bodies into their constituent parts, not as the chemist does with alembics and retorts, with re-agents and precipitates, but by means of the spectra

which these substances give when in a state of intense luminosity.

Spectrum analysis in no way supplants chemical analysis, for its function is neither to decompose nor to combine bodies, but rather to reconnoitre an unknown territory, and to signalize the presence of any substance brought beneath its scrutiny.

The delicacy of this method of investigation is such that when every other means of research is exhausted, one look in the spectroscope is often sufficient to reveal the presence of a substance. As an instance, may be quoted sodium, the chief constituent of common salt. By the use of delicate scales, and the application of special skill, the chemist may be able to discover and determine the weight of the millionth part of a kilogram of this substance, yet if that small particle be subdivided into three million parts, this minute quantity may still be unhesitatingly detected by the spectroscope. The striking together of the pages of a dusty book is even sufficient to produce a flash of yellow light—the unfailing sign of the presence of sodium—in a spectroscope placed at some distance.

It was to be expected that so sensitive a means of investigation, from which no known substance can escape, would lead to the discovery of new elements which had remained unknown, either from being sparsely diffused in nature or from being closely allied in character to some other substance.

This expectation was realized by the labours of Bunsen and Kirchhoff, to whom we are indebted, if not for the discovery of spectrum analysis, yet for the invention of the spectroscope and its application to practical science. By the use of their new apparatus they discovered the metals cæsium and rubidium, to which two others were soon after added, viz., thallium by Crookes, and indium by the joint labours of Reich and Richter.

To these new elements was added, in 1875, a fifth, gallium, which is related to zinc and cadmium, and was detected in the zincblend of Pierresitte, by Lecocq de Boisbaudran. Since then various so-called new metals have been discovered, but as they all belong to one group, and differ little one from the other, it is possible they are but modifications or alloys of metals already known.

Wonderful as have been the achievements of the spectroscope in the regions of physics and chemistry, they have been even more remarkable in the domain of astronomy. Until within a few years the telescope was the only instrument by which astronomical investigations could be carried on, and with regard to the fixed stars and nebulæ, it was powerless to do more than give information as to form, size, and colour. But since the application of spectrum analysis to astronomy the sphere of astronomical research has been vastly enlarged. By means of the prism the light of the various heavenly bodies may be decomposed and examined, and by a comparison of their spectra with the spectra of terrestrial substances, evidence may be obtained as to the existence of any of the terrestrial elements in the remote heavenly bodies.

In investigations with spectrum analysis the starting-point is the spectrum of each individual substance, and in order to obtain this it is requisite that the substance should not only be luminous, but should emit a *sufficient quantity* of light. Dark bodies are not as a rule available for spectrum analysis; if they are to be submitted to its scrutiny, they must first be brought into a state of vivid luminosity.

To avoid interruption and repetitions, it will be desirable now, before entering upon the subject of spectrum analysis, to review with brevity the means afforded by chemistry and physics for rendering luminous all substances, gaseous and non-gaseous, and even the least fusible metals.

2. The Luminous Power of Flame.

The immediate cause of the luminosity of flame has not yet been fully ascertained, notwithstanding the many investigations that have been made with this object. If a glass receiver (Fig. 1) is filled with oxygen, and a lighted piece of phosphorus is plunged into it from above, the phosphorus will burn with great energy, and give out a dazzling light. In the same manner most metals previously raised to a

Fig. 1.

Combustion of a Steel Watch-spring in Oxygen.

glowing heat, as, for instance, a steel watch-spring, will burn in pure oxygen, with the development of an intense light.

On the other hand, if a stream of hydrogen gas is ignited in free air, it will burn with a scarcely perceptible flame. The flame produced by oil, petroleum, and coal gas is very brilliant, while that from spirits of wine is faint. A flame which does not contain *solid* matter in a state of incandescence is, as a rule, but little luminous, even when the temperature of

combustion is very high; therefore, at a similarly high temperature, glowing solid or liquid bodies emit far more light than gaseous substances do; the fewer solid particles there are in a flame the less will be its luminosity. The scarcely perceptible flame of hydrogen gas will immediately become luminous if any solid body is heated in it to incandescence.

If a spiral of platinum wire is held in such a flame, it shines brightly; the glowing wire is clearly seen, and conveys the impression that the light is not due to the hydrogen flame, but to the glowing white-hot metal. It is the heat generated by the chemical combination of the hydrogen gas with the oxygen of the air which renders the platinum incandescent, and it is the glowing platinum wire, not the flame, which emits the intense light.

If a grain of common salt is dropped into the dull flame, it flashes up brightly with a yellow light. The salt is dispersed into a million of the smallest particles, which, glowing in the flame, impart their brilliancy to it.

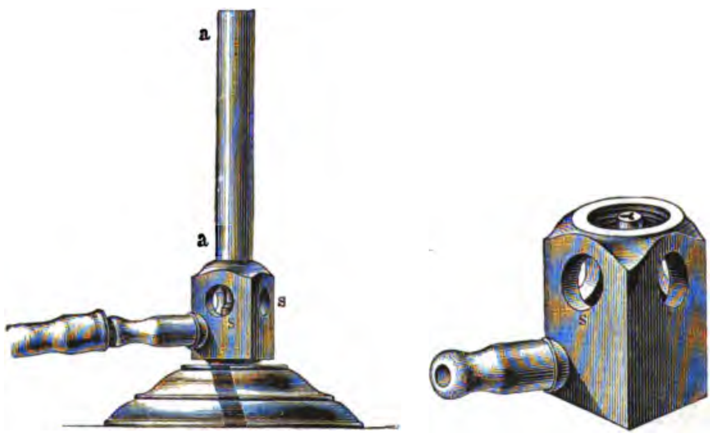
The luminous power of ordinary gas—a chemical compound of hydrogen and carbon—has been attributed in a similar manner to the presence of finely-separated particles of carbon. If oxygen is added in the form of atmospheric air, so that the carbon is more completely consumed, the flame ceases to be luminous, and, on account of the rapid combustion caused by the oxygen, the heat of the flame is enormously increased.

This explanation has been called in question by the experiments of Frankland, which tend to show that the luminosity of a flame depends mainly on the *density* of the gas, and upon this density depends, as shown by St. Claire Deville, the *temperature* of combustion. According to the recent researches of Wibel it is found that a gas flame which has been made non-luminous by the introduction of

nitrogen, carbonic acid, carbonic oxide, or hydrogen, may be restored to brilliancy merely by an elevation of temperature.

Whatever may be the cause of luminosity in an incandescent body, it is certain that incandescent, *solid*, and *liquid* bodies possess a much *greater emissive power*—that is to say, they emit a much more intense light—than gases do when rendered luminous under ordinary pressure, and that the luminous power of gases augments in proportion to the

FIG. 2.



Bunsen's Gas-burner.

pressure to which they are subjected, by which their density is increased, and they approach more nearly the condition of fluids.

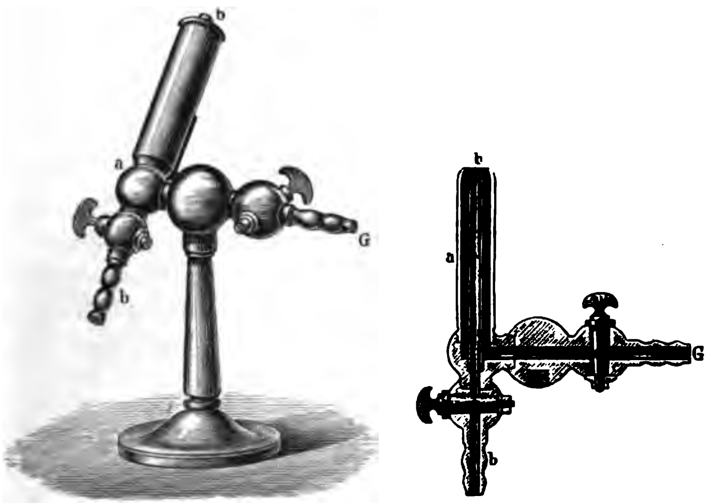
3. THE BUNSEN BURNER.

One of the most essential requisites in spectrum analysis is the Bunsen burner, by means of which an ordinary gas flame may be raised to so high a temperature that it is capable of converting the substances to be examined into a

gaseous condition, causing them to emit light sufficient to yield a distinct spectrum. The heating power of the lamp is obtained by allowing air to mix with the gas before it enters the burner. To accomplish this the lower chamber *s* (Fig. 2) is perforated so as to permit the outer air to mix plentifully with the gas before it rises in the tube *a a*.

If the burner is contrived, as is very desirable when

FIG. 3.



Bunsen's Gas-blowpipe.

working with the spectroscope, so that the entrance of air to the gas can be shut off at will, either entirely or partially —which is easily effected by turning round a perforated ring—then the same burner serves to give alternately a luminous or a heat flame.

The heat of this flame may be further increased if the air is forcibly mixed with the gas by means of a powerful blow-pipe. An apparatus of this description is shown in Fig. 3, where the gas entering from the pipe G passes through the

wide tube *a*, which is closed at the lower end by a stop-cock, and turns on a pivot round the stand. In the middle of this tube *a* runs a second narrower tube *b b*, through which the atmospheric air is forced into the stream of gas through an elastic tube by means of a bellows. The gas flame is thus supplied with so much oxygen that an enormous quantity of heat is obtained. Over the escape end slides a tube, by means of which, in conjunction with the cocks, the heat of the flame can be regulated. The greater the quantity of gas burnt in a given space, and the greater the energy and the rapidity of the combustion, the greater also will be the amount of heat evolved. For this reason, in some large laboratories, atmospheric air is forced by a special air-pump into a strong iron receiver of the capacity of several quarts, where it is subjected to a pressure of one and a half to two atmospheres. If this compressed air is allowed to escape along with a copious stream of gas from a common tube, the flame becomes one of such intense heat, that in a few minutes it can melt considerable quantities of some of the least fusible metals.

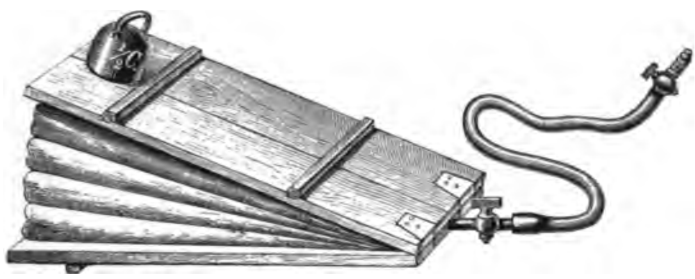
4. The Oxyhydrogen Flame and Drummond's Lime-light.

In the oxyhydrogen flame we arrive at the most powerful source of heat to be attained by *chemical* means. The flame is formed by pure hydrogen gas mixed with as much pure oxygen as will ensure its complete combustion, viz., two volumes of hydrogen with one of oxygen. The heat evolved by this flame is sufficient to fuse substances which have resisted the hottest furnaces. To avoid the danger of an explosion, the gases should not be mixed before ignition, nor allowed to flow out of the same common reservoir, as in that case the flame would spread into the interior, and cause the ignition of the whole quantity. It is necessary to arrange the apparatus

so that the gases shall reach the emission tube from separate vessels, and be allowed to mix only immediately before escaping from the burner.

The simplest arrangement of this kind is similar to that of the gas-blowpipe in Fig. 3, but with this difference, that the section of the two tubes should bear more nearly the relation of two to one. The gases are stored in two separate gas-bags (Fig. 4), whence they reach the lamp by means of pressure. The outer wide tube of the lamp must be placed in connection with the hydrogen reservoir, and the inner narrow one with that containing oxygen; both the tubes should be fitted with a fine brass-wire netting, to prevent

FIG. 4.



Gas-bag for Oxygen or Hydrogen.

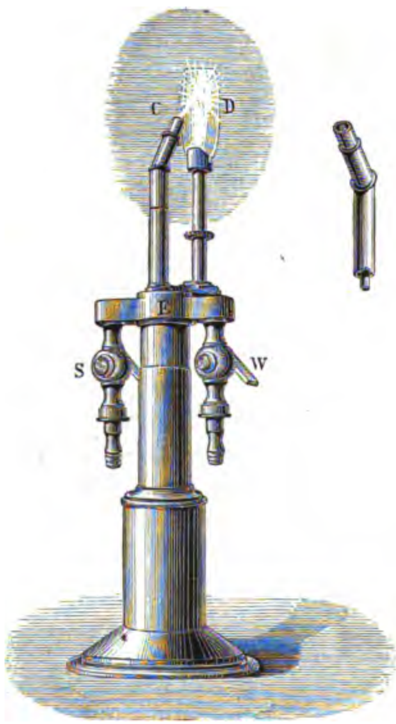
the flame retreating into the inside of the lamp, or the gas extending from one tube to the other, from any cause, such as the diminution of pressure in the reservoirs.

More convenient than the bags, in which the gases can only be kept with safety for a short time, are the wrought-iron cylinders, which are filled with the gases condensed to about twenty atmospheres. These iron bottles contain sufficient gas to maintain an ordinary oxyhydrogen light for from six to eight hours. They can be refilled with condensed gas at a small expense.

A convenient form of such a lamp applicable for heating

purposes as well as for the production of light is made by fixing the burner C to a stand (Fig. 5), with its two tubes S and W conveying oxygen and hydrogen, the upper part of the tube C being inclined sideways, and attached so as to turn in any direction. To the stand E, to which an upward and

FIG. 5.



Oxyhydrogen Blowpipe. (Drummond's Lime-light.)

downward motion is given by rack-work, is attached a carrier by which substances may be brought into the flame.

In igniting the lamp it is necessary as a preliminary to open the cock W for a few seconds, so as to allow the hydrogen to expel the atmospheric air remaining in the elastic tube: under pressure of a weight (100 lbs.) upon

the gas-bag the hydrogen burns in a long, faintly luminous flame. The oxygen cock S must then be carefully opened, —the entrance of the oxygen into the hydrogen flame being generally announced by a faint explosion,—and on gradually opening the tap the flame becomes shorter and more pointed, until its luminosity almost ceases; if the excess of hydrogen gas is shut off by turning the cock W, there will be immediately formed the small, pointed, non-luminous flame of the oxyhydrogen blowpipe.

It is needless to describe the range of wonderful experiments that can be exhibited in the lecture room by means of this flame; suffice it to say that its power of combustion is such that if a thick wire of platinum, a metal most difficult to fuse, is held in the flame, it melts immediately like wax. If a bundle of steel wire is placed in the flame, the iron splutters about in a thousand brilliant sparks like a shower of fire, and great drops of the glowing metal fall to the ground and run about in all directions.

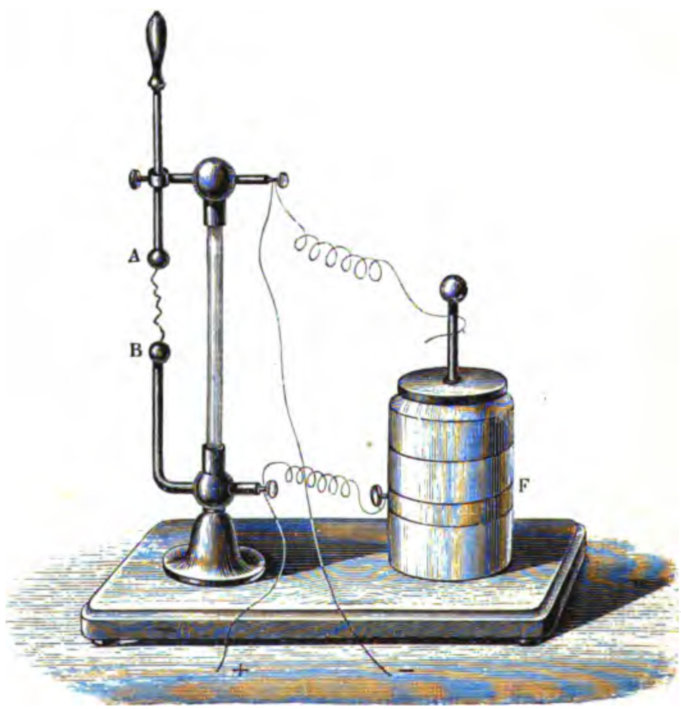
The oxyhydrogen flame may become a source of intense light if, as suggested by Drummond, a cylinder, D (Fig. 5), of well-burnt lime is placed upon the socket of the lamp, and the flame directed against its upper part: it begins at once to glow, and throws out a dazzling light. A still higher intensity may be attained by substituting a piece of magnesia or zirconia for the cylinder of lime.

5. The Electric Spark.

The greatest amount of heat and light at present attainable is furnished by electricity; and various methods for exciting it have been devised. In all electrical generators arranged for the production of light, sparks are formed between two metallic poles or pieces of wire, which are placed in contact with those parts of the machine which collect the positive and negative electricity.

The amount of heat thus generated depends upon the degree of tension and the quantities of electricity by the union of which it is produced; but in most cases it is so great that small particles of the metal poles are volatilized, and become luminous. The glowing metallic vapour affects

Fig. 6.



The Electric Spark intensified by a Condenser.

the colour of the spark, and gives rise to various qualities of light, according to the nature of the terminals. These phenomena are valuable in spectrum analysis as affording a very simple method of volatilizing and raising most of the metals, and other substances which are conductors of electricity, to a high degree of luminosity. The same result

may be obtained with liquids, by placing one of the metal poles in the liquid to be examined, and bringing the other sufficiently near the surface for the spark to pass from it to the liquid. By the heat of the spark a small portion of the liquid is volatilized and made luminous.

If the spark supplied by these machines is insufficient, and a higher degree of heat is desired, an intensifying apparatus, such as a Leyden jar, F, or a condenser, must be placed between the two metal conductors A, B (Fig. 6); the spark passes between A and B only when the condenser has become charged, and the heat evolved is in proportion to the amount of electricity collected in the condenser.

Gases can also be made luminous by the electric spark if enclosed in glass tubes and the spark be sent through them. The luminous discharge then takes a different colour according to the nature of the gas: in hydrogen gas it appears a purple-red—in chlorine, green—in nitrogen, violet—in oxygen, white; but this method is not always advisable, because the heat of the spark is insufficient at the ordinary pressure to render a large quantity of gas luminous; it will presently be seen how this object may be attained by rarefying the gas.

6. The Induction Coil.

Among the most powerful generators of electricity is the induction coil, by means of which a comparatively weak electric current acting on every part of a thin wire many thousand feet in length, and completely insulated, produces electric sparks of such length and tension that they may bear some comparison even with lightning. As the induction coil, when once set to work, will continue to act so long as the exciting battery is in order, it is more suited to the requirements of spectrum analysis than are those machines in which electricity is generated by manual labour. The larger instru-

ments of this kind are called, after their inventor, Ruhmkorff's Induction Coils, and are now so constructed that with moderate dimensions they give sparks from twelve to sixteen inches in length. For most purposes in spectrum analysis, however, an induction coil of medium strength is sufficient.

7. Luminosity of Gases; Geissler's Tubes.

Experience has long shown that gases in a rarefied condition are good conductors of electricity, while they are without exception bad conductors when in a state of greater density. Before the introduction of spectrum analysis into science, it was known that in an egg-shaped glass vessel (Fig. 7) in which the air had been rarefied by an ordinary air-pump to a pressure of from $\frac{1}{12}$ to $\frac{1}{8}$ of an inch of mercury, an electric current could pass with the greatest readiness, taking the form of a luminous arch, between the metal knobs enclosed in the air-tight vessel, even when these knobs were eight or ten inches apart. An envelope of blue light surrounded the ball by which the negative current entered, and a brush of reddish light was emitted from the positive ball.

Fig. 7.

Electric Egg.

If small quantities of the vapours of certain substances, such as alcohol, phosphorus, or turpentine, are introduced into such a glass vessel before exhausting the air, the spray of light will not merely be coloured according to the nature of these vapours, but there will be also a series of dark stripes breaking crossways through the light, which therefore, as it travels from the metal knobs, will no longer be continuous, but be interrupted by dark striæ.

An incitement has been given to the study of these phenomena by Dr. Geissler's discovery of a new method of rarefying air. He succeeded in producing vacua in glass tubes, in which gases could be enclosed in a state of extreme tenuity. By means of platinum wires soldered at either end, the tubes can be brought into connection with the poles of an induction coil.

FIG. 8.

Geissler's Tube.

These phenomena vary exceedingly according to the form and composition of the glass of which each portion of the tube is composed, but especially according to the nature of the gas enclosed, and its degree of tenuity. Fig. 8 shows a Compound Geissler's tube of this kind. When in contact with the poles of the induction coil, and the gas rendered luminous by the passage of the electric current, those portions of the tube which are filled with rarefied atmospheric air, or nitrogen, emit a beautiful ruddy light; whilst carbonic acid and carburetted hydrogens give out green and white tints. In a dark room these tubes present a splendid spectacle by the alternate stria of dark and brilliant parts, the purity of the colours, and the variety of forms into which the glass has been manufactured.

Geissler's tubes furnish a very convenient means for rendering any gas luminous; but the intensity of the light is rarely sufficient for the purposes of spectrum analysis,

as the spectrum of such a tube can be examined only when every other light is withdrawn. Professor Plücker, however, succeeded in concentrating this faint light by confining the gases in very narrow capillary tubes.

Fig. 9.

Plücker's Tube.

Let us examine a series of Plücker's tubes as prepared for the purposes of spectrum analysis. The first of these is almost reduced to a vacuum—at least the small amount of gas in it does not produce a greater pressure than $\frac{1}{250}$ of an inch of mercury; the second tube (Fig. 9), where the central portion *a b* is capillary, encloses extremely rarefied hydrogen gas, the third nitrogen, the others oxygen, chlorine, carbonic acid, and minute traces of the vapours of iodine, sulphur, mercury, selenium, etc. If these tubes are brought singly into connection with an induction coil, in order that the current may pass between the platinum wires A and B, and render the gas enclosed luminous, the first tube shows no appearance of light, although the wires are barely separated $\frac{1}{25}$ of an inch, and the spark could be discharged in air at the distance of two or three inches. It would therefore appear that the electric current requires a material conductor for its transmission from one wire to the other, and that it cannot pass where there is no trace of either gas or vapour—that is to say, *in vacuo*. In the other tubes, however, the light passes through the narrow portion *a b* with considerable intensity, and is visible at some distance as a sharply defined line, bearing a very decided colour peculiar to the luminous gas.

By the investigations of Hasselberg and Wiedemann it has been demonstrated that under the influence of the electric current, gases in a condition of extreme rarefaction may become luminous at a temperature far below that of incandescence. Thus during the experiments the glass tube under a pressure of gas at ·025 inches may become heated, and rise to a temperature of 336°; this is still far from the temperature of incandescence. In other experiments the increase of temperature within the tube may not exceed 10° or 15°. Thus, owing to the uncertainty of measurement, it may well be

FIG. 10.

Bunsen's Battery.

questioned whether under such conditions any measurable rise of temperature takes place in the luminous gas.

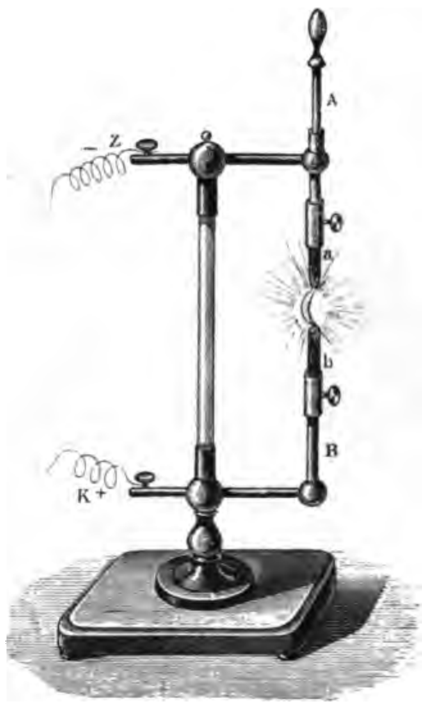
8. The Voltaic Arc; The Electric Light.

The form of electricity which yields the largest quantities of light and heat is that of the voltaic arc, or the electric light.

The voltaic arc is produced by the passage of an electric current between two carbon rods, forming the terminals of the poles of a battery. When the poles C Z of a powerful voltaic battery—such as a Bunsen battery of 50 or 60 elements (Fig. 10)—are connected by metal

wires with two pieces of carbon, *a b*, pointed at the ends (Fig. 11), and these brought into contact by bringing down the upper metal rod A, which carries the negative carbon, the electric current, in passing from one carbon to the other, produces an extraordinarily intense light. Direct contact is

FIG. 11.

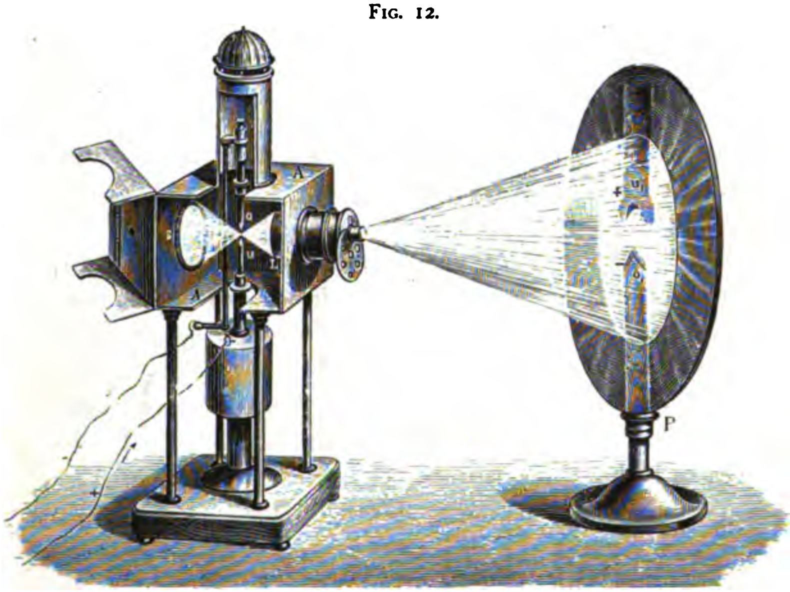


The Electric Light.

necessary to form the arc, since the current is unable to overcome the resistance of even a small stratum of air such as would prove no impediment to the electricity from an induction coil; but when the arc is once formed the points may be separated one or two-tenths of an inch without interrupting the dis-

charge. A separation to this amount increases the brilliancy of the light, but if the points are still further separated, the light is suddenly extinguished, as the electric current can no longer overcome the resistance of the intervening stratum of air. If by pushing down the rod A the points are again brought into contact (reproducing the light), then separated a little, and the machine left to itself, it will

FIG. 12.



Projection of the Voltaic Arc.

presently be noticed, if viewed through a dark glass, that the carbon is being consumed and its form constantly changing.*

* [For producing the voltaic arc, these batteries, which are cumbrous and quickly exhausted, have of late been superseded by electro-magnetic or electro-dynamic machines, which, being worked by powerful steam or gas-engines, generate, by the conversion of mechanical power into electricity, so strong an electric current that when passed between the carbon points the light and heat obtained is the most intense it is possible to produce.]

There is a risk to the eyes if a near inspection of this dazzling light is made, and as dark glasses obscure the delicate changes which are taking place, it is advisable to view it indirectly by throwing an enlarged image of the incandescent carbons upon a screen.

For this purpose the room must be darkened, and an apparatus arranged for holding the carbon points as in Fig. 12.* The lamp A is provided with a lens L of suitable focal distance, placed in front of the carbon rods, and a concave reflecting mirror S behind them; a diaphragm with different-sized holes is placed before the lens, and an opening selected of medium size—about one-eighth of an inch. The electric current is then allowed to pass, and the lens adjusted until the image is distinct on the screen P, placed about a dozen feet from the lamp. With this image (Fig. 13), in which the carbon points are magnified some hundred times, the slight changes taking place in their shape and appearance can be readily observed. It will be noticed at the first glance that an intense light is emitted by the incandescent carbon, and that the flame flickering between the points—the *voltaic arc*—is comparatively but little luminous. It will be remarked also that one of the carbon points begins to increase at the expense of the other; that which first loses its point and wastes the fastest is always the one which is in connection with the positive pole (the carbon pole) of the battery.† Very intensely bright particles pass from time to

* In the drawing, this is made to appear open at the side, to show the arrangement of the carbon points *o u*, the lens L, and the reflector S. In reality, the lamp is shut close up after receiving the carbon holder. The junction of the carbon points corresponds with the geometric centre of the mirror, so that the rays from the voltaic arc falling on the mirror are reflected back to their starting-place, and thence proceed in company with the direct rays from the arc to the lens L.

† [It also emits the most intense light, and is hotter than the negative pole.]

time from the positive to the negative carbon ; little globules of melted silica, a substance always to be found even in the

FIG. 13.

The Carbon Points of the Electric Light. (Highly magnified.)

purest carbon rods, are to be seen gliding over the surface of the carbon ; these are the enemies of the electric light, for by their motion they give a certain irregularity to the

arc, and as they are less brilliant than the carbon, they diminish the intensity of the light. When these globules, by their erratic movements, reach the hottest part of the points whence the strongest light is emitted, their presence is known by a hissing noise, and unfortunately also by a sudden diminution of the light.

When the carbon points have become so separated that the current has difficulty in passing through the air from one pole to the other, by means of the incandescent particles, the strength of the current suddenly diminishes, and in like proportion the light begins to wane, until it is finally extinguished through the further separation of the carbon points.

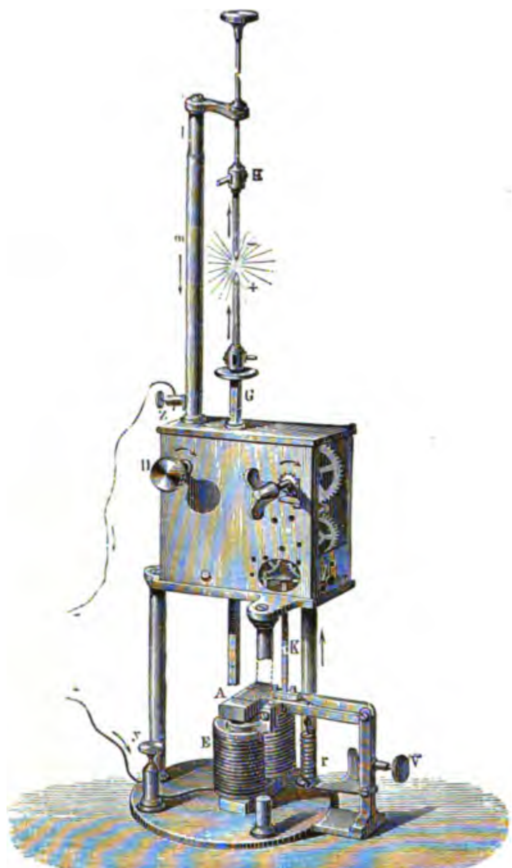
9. The Electric Lamp.

The chief obstacle to the employment of this magnificent light was its extreme uncertainty, and the ingenuity of scientific and practical men has been directed to devise an apparatus for keeping the carbon points at the requisite distance notwithstanding the constant waste of combustion. This has been successfully accomplished in Foucault's electric lamp (Fig. 14), in which by an ingenious arrangement the magnetic power of the voltaic current itself becomes the regulator of the carbon points.

The intensity of the heat and light from the voltaic arc, though much affected by the purity of the carbon points, depends principally upon the amount of electricity generated, and therefore on the size, number, and nature of the elements employed. With a medium-sized battery, consisting of 50 or 60 of Bunsen's or Grove's elements, the light varies from that of 400 to 1,000 stearine candles, according to the purity of the carbon points, and their distance from one another. Fizeau and Foucault have

compared the chemical power of the electric light with that of the sun, by means of iodized silver plates, and found that

Fig. 14.



Foucault's Electric Lamp.

the electric light from a Bunsen battery of 46 elements could be expressed by the number 235, supposing sunlight at noon on an August day to be represented by 1,000.

The light from a Bunsen battery of 100 elements produces much discomfort to the eyes;. a single glance is sufficient, when 600 elements are employed, to occasion considerable injury to the eye, and a long-continued headache. Even when only 60 elements are used, it is desirable to avoid looking directly at the naked light, and to make use of deep-blue spectacles during the experiments.

PART SECOND.

SPECTRUM ANALYSIS IN ITS APPLICATION TO TERRESTRIAL SUBSTANCES.

SPECTRUM ANALYSIS

IN ITS APPLICATION TO

TERRESTRIAL SUBSTANCES.

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10. Light.

Although the theory of light is now so complete that it offers an explanation of the most complicated optical phenomena, yet the great question as to the nature of light is for the most part unanswered. The operation of light is everywhere apparent, and is so manifold in effect, that the sun, while shedding forth but a single tone of colour, invests individual objects with an infinite variety of tints. The investigation of these colours and their development from the white light emanating from the sun constitutes pre-eminently the province of Spectrum Analysis.

According to the theory at present received, the universe is an immeasurable sea of highly attenuated matter, imperceptible to the senses, in which the heavenly bodies move with scarcely any resistance. This fluid, which is called *ether*, fills the whole of space—fills the intervals between the heavenly bodies, as well as the pores* or interstices between

* The hypothesis that atmospheric air in a condition of extreme attenuation is to be placed in the room of ether is yet too vague and too little supported by optical phenomena to be here entertained.

the atoms of a substance. The smallest particles of this extremely delicate and highly elastic substance are in constant vibratory motion; when this motion is communicated to the retina of the eye, it produces, if the impression upon the nerves is sufficiently strong,* a sensation which we call *light.*

Every substance, therefore, which sets the ether in powerful vibration is luminous; strong vibrations are perceived as intense light, and weak vibrations as faint light, but in space both of them proceed from the luminous object at the extraordinary speed of 186,000 miles in a second, and they necessarily diminish in strength in proportion as they spread themselves over a greater space.

Light is not therefore matter *per se,* but only the vibration of matter, which, according to its various conditions of motion, gives rise to light, heat, or electricity.

11. Analogy between Light and Sound.

This representation of the nature of light ceases to be surprising when we compare the vibrations of ether with those of atmospheric air, and draw a parallel between light and sound—between the eye and the ear.

A string set in vibration causes a periodic movement of the air which is transmitted at the rate of about 1,100 feet in a second; it strikes against the tympanum of the ear, and occasions, by its further impulse on the auditory nerves and brain, the sensation we call *sound.* Air in motion, by its influence on the organs of hearing, is the cause of sound; ether in motion, by its influence on the organs of sight, is the cause of light. Without air, or some other medium

* [It will be seen later that something besides strength is required to make the indication luminous.]

whereby the vibration of bodies can be propagated to our ears, no sound is possible.

A musical sound, in contradistinction to mere noise, is produced only when the impulses of the air occur at *regular* intervals. The pitch of a musical note depends on the number of impulses in a given time, as, for instance, in a second; the greater the number of vibrations in a second, the higher will be the note produced. When the single impulses are fewer than 16 or more than 40,000 in a second, the ear is no longer sensible of a musical sound: in the first case it either perceives only an undefined deep hum, or else it distinguishes the individual strokes upon the tympanum, and becomes sensible of them as distinct blows; in the latter case there is an impression of a sharp but equally indefinite shrill or hissing noise.

Colours are to the eye what musical tones are to the ear. A certain number of ether impulses in a second striking the retina of the eye are necessary to produce the sensation of light: if the number of these waves pass above or below a certain limit, the eye is no longer sensible of them as *light.* The first sensation of these vibrations commences at about 450 billion impulses in a second, and the eye ceases to perceive them when they have reached double this number, or about 800 billion; in the first case the impression produced is that of dark red, in the latter of violet.

The greater the number of vibrations in any given time, the more rapidly must the single impulses succeed each other; it may be concluded, therefore, that the different colours are only produced by the different degrees of rapidity with which the ether vibrations recur, just as the various notes in music depend upon the rapidity of the succession of vibrations of air. The vibrations which recur most slowly—amounting, however, to at least 450 billion in a second—give the sensation of red; those recurring more

rapidly produce that of yellow; and if the rapidity continues to increase, the sensation becomes in succession green, blue, and violet, beyond which the eye is no longer sensitive to the ether motion, though this is still far from having attained its maximum.

Those slower vibrations which, though they are reckoned by billions in a second, do not amount to 450 billion, are made apparent to us in the sensation of heat, which is also the result of oscillatory movement, radiant heat being, like light, propagated without the aid of foreign bodies. Those vibrations, on the other hand, which have a shorter period than that by which violet is produced—at which colour the eye's susceptibility to light ceases—reveal themselves by their powerful chemical action *; they succeed each other too rapidly for the visual nerves to be any longer conscious of the impulses, but they have the power of working chemical changes, and the decomposition of various substances can undoubtedly be traced to the agency of these invisible rays. There are various substances which possess the power of moderating the excessive velocity of these vibrations, and thus bringing the invisible chemical rays within the reach of the eye's susceptibility. These substances, termed *fluorescent*, appear illuminated when placed beyond the visible limit of the spectrum, and receive only those rays which vibrate more than 800 billion times a second.

12. Refraction of Light.

When light passes through a stratum of air, water, or glass, a portion of the ether motion appears to be destroyed—*absorbed;* and this absorption is the greater the further the

* [It must not be understood that these rays *alone* have the power of causing chemical decomposition. The whole of the rays of the spectrum have the same power.]

distance the light has to travel through these bodies. Thus objects are seen with perfect distinctness through a thin sheet of glass, while through a thick piece they are less clearly visible, and are sometimes almost obliterated.

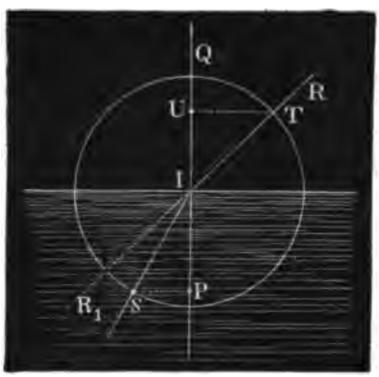
So long as light passes through a completely homogeneous medium possessing the same density throughout, it is transmitted with unvarying rapidity in a straight line; but this is not the case when it passes from one medium to another of different constitution. When, for example, a ray of light coming through the air strikes upon the surface of water, or upon a sheet of glass, and afterwards passes through these denser substances, it deviates from its straight course the moment it touches the new medium, excepting only when it falls perpendicularly to the surface separating the two media.

This deviation of the ray of light from its straight course is called *refraction:* it occurs in all cases where light passes obliquely from one medium to another of different density or constitution. The laws of refraction have been ascertained with mathematical precision, and it will be desirable to consider here some of the most important of them. If, for example, the ray R I (Fig. 15) passes from the air into water at I, it will pursue its path through the water, not in continuation of the straight line R I, therefore not in the direction of I R^1, but in that of I S, which is nearer than I R^1 to the perpendicular I Q erected on the surface of the water at the point I. The refracted ray I S remains in the same plane R I Q formed by the incident ray R I with the perpendicular I Q, and in this plane the angle R I Q formed by the ray R I with the perpendicular Q P in the rarer medium (air) is, with very few exceptions, greater than the angle S I P formed by the ray I S with the perpendicular Q P in the denser medium (water, glass, etc.). On passing from a rarer into a denser medium the ray is usually bent *towards* the perpendicular in the denser medium; and,

conversely, on passing out again from the denser into the rarer medium, it is bent *from* the perpendicular.

The relative proportions of the two angles R I Q and S I P may be ascertained by describing a circle with any radius from the point I, and letting fall the perpendiculars T U and S P from the points of intersection T and S upon the line Q P. These perpendiculars are measures of what are called the *sines* of the angle which they enclose; thus, T U is a measure of the sine of the angle of incidence T I U,

FIG. 15.



Refraction.

and S P is that of the sine of the angle of refraction S I P, and the sines are subject to the following universal law of refraction: ***For the same two media the proportion of the sines of the angles of incidence and refraction is a constant quantity, whatever may be the angle of incidence.***

This proportion (T U : S P) is, for example, for air and water as 4 to 3, whence it follows that at whatever angle the ray R I in the air may strike the surface of the water, the refracted ray I S will be so deflected that T U shall be to S P in the proportion of 4 to 3.

This invariable ratio between the sines of the angles of

incidence and refraction is called the *index of refraction* of the media. The index of refraction for air and water is therefore expressed by 4 : 3, or more accurately by 1·34. Every transparent medium has a peculiar and special index of refraction, and this again varies even in the same substance according to its greater or lesser density. Thus for air and crown glass the index of refraction is 1·530, while for air and dense flint glass it is 1·645; the refracting power, therefore, of flint glass is much greater than that of crown glass under similar conditions.

The following table gives the mean value of the indices of refraction for several substances when light enters them from the air:—

Water	1·337
Alcohol	1·374
Canada balsam	1·532
Bisulphide of Carbon	1·680
Crown glass, No. 13 of Fraunhofer	1·531
Flint glass, No. 30 of Fraunhofer	1·637
Flint glass of Merz	1·761
Diamond	2·487

The angle S I R, formed by the deviation of the refracted ray I S from the incident ray R I R, is termed the *angle of deviation.* This angle is manifestly the difference between the angle of incidence R I Q and the corresponding angle of refraction S I P. The amount of deviation increases with the increase of the angle of incidence, but does so at a proportionally greater rate. This will be at once apparent from the following tables, calculated for the media of air and water, based upon their refractive index of 4 : 3, in which the successive angles of refraction formed in the water corresponding with every 10° increase in the angle of incidence in the air are given.

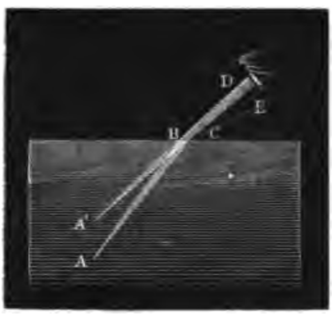
Angle of Incidence in the Air.	Angle of Refraction in the Water.	Difference between the Successive Angles of Refraction.	Deviation.
0°	0°		0°
10	7° 29′ 0″	7° 29′ 0″	2° 31′ 0″
20	14 51 48	7 22 48	5 8 12
30	22 1 27	7 9 39	7 58 33
40	28 49 26	6 47 59	11 10 34
50	35 4 0	6 14 34	14 56 0
60	40 30 20	5 26 20	19 29 40
70	44 48 41	4 18 21	25 11 19
80	47 36 45	2 48 4	32 23 15
90	48 35 25	0 58 40	41 24 35

While therefore the angle of incidence in the air augments progressively 10° at each advance, the angle of refraction in the water increases at a slower rate, and only attains its maximum—48° 35′ 25″—when the angle of incidence has reached 90°. The last column of figures shows the progressive increase in the deviation with a constant increase of 10° in the angle of incidence. When the ray passes from water to air the increase in the deviation, as the angle of incidence increases, is still greater. In this case the result is as follows:—

Angle of Incidence in Water.	Angle of Refraction in Air.	Deviation of the Ray.
0°	0°	0°
5	6° 40′ 24″	1° 40′ 24″
10	13 23 14	3 23 14
15	20 11 16	5 11 16
20	27 7 53	7 7 53
25	34 17 58	9 17 53
30	41 48 39	11 48 39
35	49 53 11	14 53 11
40	58 59 15	18 59 15
45	70 31 50	25 31 50
48° 35′ 25″	90 0 0	41 24 35

It appears therefore that in the passage of a ray of light from air to water, when the angle of incidence is 90° the angle of refraction is 48° 35′ 25″, while a ray falling perpendicularly passes through unbroken. Between the angles of incidence 0° and 90° in the air lie a countless number of rays; while in the water all their corresponding angles of refraction are confined between 0° and 48° 35′ 25″, and no refracted ray can fall beyond this limit. This angle is therefore named *the limiting angle* of refraction in this medium, and is found by the equation $\frac{\sin. 90°}{\sin. x} = P$, where P

FIG. 16.

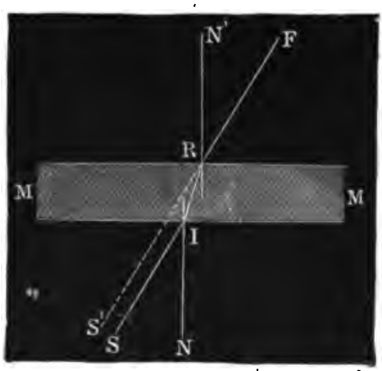


Refraction by a Liquid.

is the index of refraction from the rarer to the denser medium, or by $\sin. x = \frac{1}{P}$. For air and glass this angle, assuming that $P = 1{\cdot}5$, will be 41° 48′ 39″. If, on the contrary, a ray emerging from a denser medium—as, for instance, glass—falls at an angle smaller than the limiting angle, say at 42°, it becomes refracted, and passes into the rarer medium. Should the ray, however, fall at an angle greater than the limiting angle, it cannot emerge from the denser medium. In this case, instead of being refracted it will be reflected from the outer surfaces of both media. This phenomenon is termed *total reflection*, and this *limiting angle* is called *the angle of total reflection*, or *critical* angle.

In Fig. 16 the ray A B emerging from point A in a liquid is refracted at B and deflected to B D; the second and closely approximate ray A C is refracted at C and proceeds through the air in the direction C E. Now as the angle of refraction increases with the angle of incidence, the refracted rays B D and C E diverge in the same manner as the incident rays A B and A C. If these rays are prolonged, they unite at the point A^1, and to an eye receiving the bundle of rays comprised between B D and C E the same

FIG. 17.



Path of the Rays through a Medium with Parallel Sides.

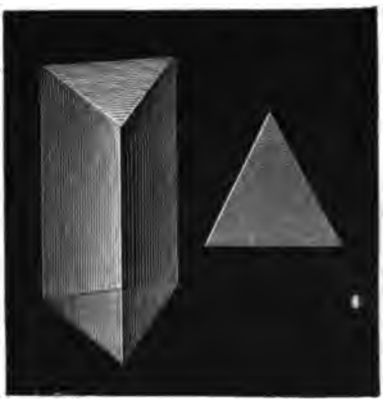
impression will be produced by the condensing power of the lens as if the rays came unrefracted from the point A^1. The eye thus sees the point A at A^1, which is the optical image of A made to appear there by refraction. A^1 is higher than A, and this explains why objects under water are made to appear higher by refraction than they really are.

13. REFRACTION THROUGH GLASS OF PARALLEL SURFACES.

If a ray of light, as S I in Fig. 17, is transmitted from the air through a denser medium, M M, with parallel sides,—

for example, through a plate of glass,—then a simple construction deduced from the preceding law will show that the incident ray S I will be diverted at I towards the perpendicular I N in the direction I R, but that on its emergence from the glass at R, it will again deviate by an *equal* amount from the perpendicular R N^1, so that in whatever direction the incident ray S I may fall, the emergent ray R F always remains parallel to it. A spectator at F, on the opposite side of the glass plate M M, would receive the incident ray

FIG. 18.



The Prism.

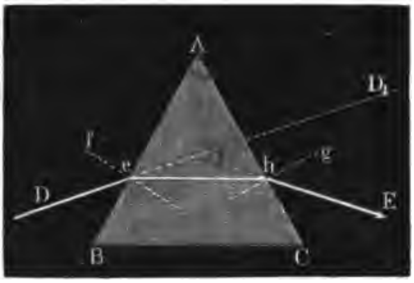
S I in the direction R F, and would see the luminous point S, whence the ray S I emanated, in the direction R S^1, so that this point would appear in a different place, S^1, from that which it really occupies.

14. REFRACTION OF MONOCHROMATIC LIGHT BY A PRISM.

If the surfaces of the glass, instead of being parallel, form an angle with each other—as in a triangular glass prism (Fig. 18)—the path of a ray of light will be as follows. Let A B C (Fig. 19) represent the section of a prism

standing on its base, and let the ray D *e* fall in the plane of the section upon the surface A B. The ray on entering the glass is bent towards the perpendicular *f e* in the direction *e h*. After passing through the prism in a straight course, it is again bent at *h* on emerging into the air, and is permanently deflected from the perpendicular *g h* in the direction *h* E. The ray D *e* therefore takes the direction D *e h* E when a prism is interposed in its path, while were the prism removed, it would pursue its original course along the straight line D D_1.

FIG. 19.



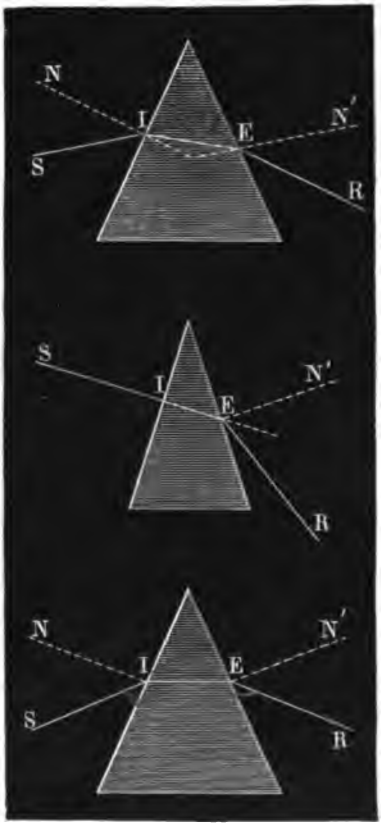
Path of a Ray of Light through a Prism.

It will thus be seen that the incident ray D *e* does not leave the prism, either in its original direction, or in a parallel direction: theory and experience have both established that *in every case* the incident ray is deflected from its original course in such a manner that the emergent ray is bent towards that surface of the prism (the base) through which it does not pass. The edge A opposite the base C B is called the *refracting edge*; the solid angle B A C formed at that point the *refracting angle;* and the angle formed by the emergent ray (*h* E) with the course D D_1 of the incident ray is called the *angle of deviation.*

Fig. 20 will illustrate this more clearly: the incident ray

S I passes through the prism after its first refraction at I in the direction I E; it becomes refracted a second time as it emerges at E, and then proceeds in the direction E R. In all the three figures the dotted lines I N and E N′ are drawn perpendicular to the surfaces of the glass; the ray is deflected in the denser medium of the glass towards this perpendicular, while it is bent away from it in the rarer medium of air, so that the angle it makes with the perpendicular is always greater in the air than in the glass. In the second figure the incident ray S I passes unrefracted through the prism in the direction I E, because S I is perpendicular to the surface of the prism. In the third figure the incident ray S I and the emergent ray E R form the same angle with the surfaces of the prism, and this is also the case with the refracted ray I E. The path taken by the ray in this case is termed the *symmetrical* path of a ray, and it is at this point that the *minimum of deviation* occurs.*

FIG. 20.



Refraction of a Ray of Light by a Prism.

* See Appendix A.

The determination of this angle of minimum of deviation is of great importance in all investigations concerning the refraction of light and the analysis of the spectrum, not only because it furnishes a ready method for ascertaining the co-efficient of refraction for the prism, but because it also indicates that portion of the prism through which objects are seen without distortion.

We are prepared to understand from Fig. 16 that the emergent rays D (Fig. 21), after their first refraction by the prism A B C, appear to form an image at *d* when viewed in the direction *h e*. This image again may be regarded as a starting-point of rays, which, travelling in the direction *e h*,

FIG. 21.

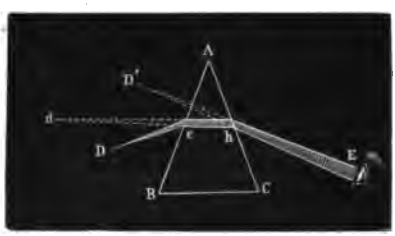


Image beyond the Prism.

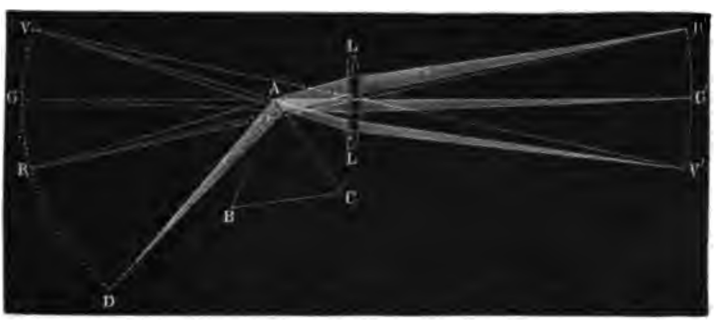
suffer a second refraction at the point of emergence *h*, and proceed through the air in the direction *h* E to the eye at E. Thus it happens that when viewed in the direction of the emergent rays an image is seen beyond the prism at the point D′.

By calculation it is found that with the minimum of deviation the distance of this image D′ from the prism is equal to the distance D *e* of the luminous point; if therefore D consists of a succession of luminous points, or of a narrow luminous slit, parallel to the refracting edge A of the prism, and the eye is brought into the direction of the emergent rays *h* E, then a sharp image of the slit will be seen at D′,

and this image will appear to be at the same distance from the prism as the luminous slit D when the prism is in the position of minimum deviation. Instead of viewing the image D′ of the slit with the naked eye, it may, like any other object requiring more minute inspection, be examined with a telescope.

If, as in Fig. 22, a convex lens L is placed in the path of the emergent rays, which behave as if originating from the point D′, then, in accordance with the laws of optics, these rays will be re-united at the point *b*. This point is the image of the luminous point D, and if a screen is placed at

FIG. 22.

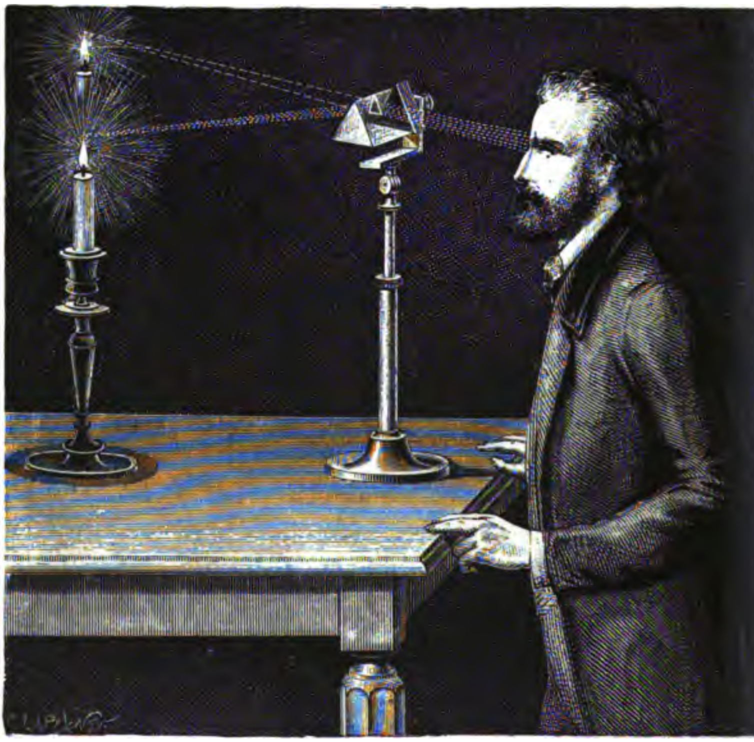


Prism with Convex Lens.

this spot, and the point D becomes a brightly illuminated slit, an inverted image of the slit will be formed at *b*. In these phenomena it is understood that the light proceeding from D is homogeneous—such as is produced by a faintly luminous flame of a spirit lamp when made yellow by the presence of common salt. If such a flame is placed in front of the slit D, or in front of a prism as in Fig. 23, and viewed through the prism, the deflected image of the slit or flame will be seen at the more elevated point D′; if the prism is inverted, the rays will be deflected from above, and the slit or flame will be in a lower position. By projecting

the image on to a screen by means of a convex lens L, a sharply defined yellow image of the slit or flame *b* will appear.

FIG. 23.



Viewing Objects through a Prism.

15. Refraction of the Different Colours by a Prism.

We have hitherto considered the phenomena of refraction only so far as they are common to rays of every description. Let us now direct our attention to the influence of refraction upon the individual coloured rays. To commence with red

light: let a diaphragm, in which is a circular hole of about one-eighth of an inch in diameter, be placed immediately in front of the lantern A (Fig. 24), and the aperture covered with a thin piece of glass *m*, coloured red with cuprous oxide. By interposing the lens L, a small red circular disc A_1, the image of the aperture A will be seen immediately opposite on the screen S S. If the glass prism *n p o* is inserted in the path of the ray between L and A_1, in the place indicated in the figure, the red disc on the screen will move from A_1 to R. The light from A which fell upon the prism in the direction A B is thus considerably diverted from its straight course A A_1, so that the emergent ray C R has moved further away from the edge *n*, where the two refracting glass surfaces unite, and has been deflected towards *p o*, the base of the prism.

Fig. 24.

Deviations of the different coloured Rays in passing through a Prism.

If green light is examined by the interposition of a green glass, the ray emerging near C no longer falls upon the screen at R, but at the point G, which lies still nearer the base of the prism *p o*, from which it may be concluded that green light is more deflected from the original direction than is red. If, finally, a violet glass is placed before the aperture, the violet ray is yet more refracted by its passage through the prism than the green was, for it strikes the screen at V. This experiment may be repeated with orange, yellow, blue, and other coloured glass; and it will be found that the place of the image on the screen changes with every colour, that the red light is the least and the violet the most refracted, and that the refrangibility of the different colours continues to increase from red through orange, yellow, green, and blue to violet.

If a ray of light, composed of several colours, is allowed to pass through a prism, the individual colours will be but slightly separated on entering the prism, but will be much more widely dispersed as they leave it. The incident ray will be decomposed into its constituent colours, and each colour will follow its separate path and appear upon the screen in the order just given.

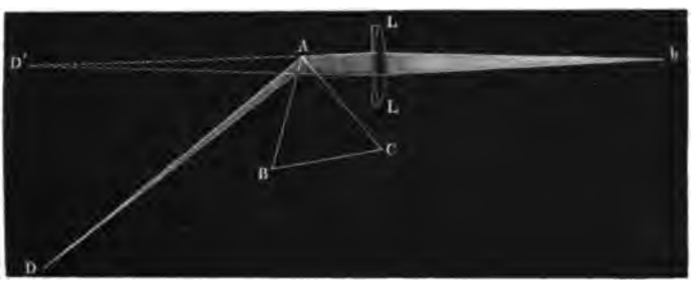
These simple experiments show that *rays of light of different colours possess different degrees of refrangibility;* red light is not so much deflected from its straight course by refraction as is violet: the former, therefore, is less refrangible than the latter. This different behaviour of red and violet light is a necessary consequence of the unequal rapidity of the ether vibrations, which we have already recognised as the cause of the different colours. In red light the number of vibrations in a second is about 450 billion, the wave-length or extent of each vibration being about $\frac{271}{10,000,000}$th of an inch. In violet light the number of vibrations in a second is about 800 billion, the wave-length being about $\frac{155}{10,000,000}$th of an inch. This difference in wave-length does not imply that the vibrations are not propagated with equal rapidity; as a matter of fact, the rays of different colours travel with the same velocity in the free ether of the universe, and almost with an identical rapidity in air. If, however, different coloured rays pass from one medium to another,—as from air to glass,—the rays of shortest wave-length are the most influenced by the increased resistance which the glass offers to the passage of the light, and are consequently the most refracted.

As each colour has a length of wave peculiar to itself, so also has it a particular degree of refrangibility; and therefore a beam of light composed of several coloured rays will be decomposed on passing through a refractive substance and separated, according to the various degrees

of refrangibility of the rays, into the individual colours composing it.

Now it is one of the laws of optics that when light passes from one medium to another the index of refraction is always proportional to the velocity of light in the two media. The index of refraction for air and water being 4 : 3, the difference of velocity of light in air and in water will be as 4 to 3 : the higher refrangibility of a ray betokens its slower speed through the refracting medium. It follows, therefore, that as in a refracting medium the various coloured rays have various indices of refraction, least in

FIG. 25.



Decomposition of White Light.

the red and greatest in the violet, they too must travel through the medium with varying velocity, the red with the greatest, the violet with the least velocity.

It will be seen from Fig. 25 what the effect must be if, instead of homogeneous light, a composite ray made up of rays of light of several colours and various degrees of refrangibility falls from the point D upon the prism A B C. As the red rays are less refracted than the yellow rays, they unite upon their exit from the prism at the point R^1, which is less removed from the line of incidence D A than is the point at G^1, the place of union of the yellow rays. The reverse takes place with regard to the violet rays, for they

unite after refraction at the point V^1, which is further removed from the line of incidence than the point G^1, where the yellow rays unite. If therefore the light from D falling on the prism D A consists of various rays of unequal refrangibility, these become separated in their passage through the prism, and appear upon the screen as a succession of coloured images between R^1 and V^1. If a brightly illuminated slit occupies the place of the point D, a succession of as many coloured images of the slit as there are varieties of refrangibility in the light by which it is illuminated will appear on the screen.

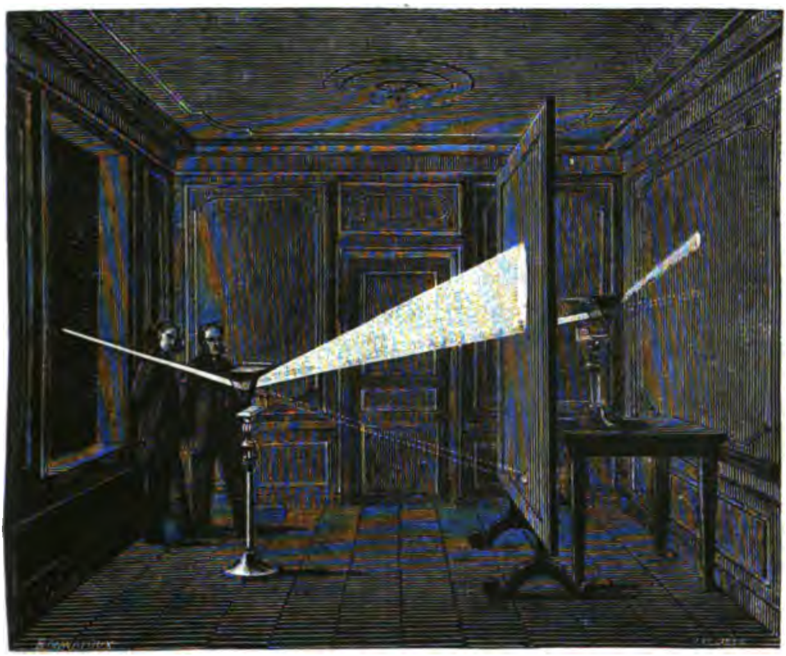
16. The Solar Spectrum.

The question now presents itself as to how *colourless*—that is to say, *white*—light is affected by its passage through a prism. Such is the light that comes to us from the sun.

If a ray of sunshine is allowed to pass through a small round hole in the window shutter of a darkened room, as is shown in Fig. 26, there will appear a round white spot of light, exactly in the direction of the ray, upon a screen placed opposite the opening, which is indicated by the dotted lines in the figure. A very different appearance will be presented if the ray of light is made to fall upon a prism. The ray is at once deflected upwards from its straight course, that is to say, towards the base of the prism, and away from the refracting edge, which, as represented in the drawing, is turned downwards. On its emergence from the prism it no longer remains one single ray, as it entered the window shutter, but is separated into various coloured rays, which, as they continue to diverge, form upon the screen an elongated band of brilliant colours, instead of the former round white image of the sun. In this brilliant band the individual colours blend gradually one into the other; beginning at that end lying nearest the direction of the

incident beam (the lowest end in the figure), with the least refrangible ray, is a dark and very beautiful red; this passes imperceptibly into orange, and orange again into bright yellow; a pure green succeeds, which is shaded off into a brilliant blue, followed by a rich deep indigo; a delicate purple leads finally to a soft violet, by which

FIG. 26.



Exhibition of the Solar Spectrum.

the range of the visible rays is terminated. A faint picture of this magnificent solar image is given in No. 1 of the coloured plate (Plate XIV.); this is called the *Spectrum.* In the colours of the solar spectrum the eye discerns numberless gradations, passing imperceptibly from one to another; and since language does not suffice to give separate names to

4

each of these, we must content ourselves with designating only the principal groups, commonly known as the ***seven colours of the spectrum.****

This experiment furnishes conclusive evidence that white light is not simple and indivisible, but composed of innumerable coloured rays, each of which possesses its own peculiar degree of refrangibility, and therefore, on refraction, pursues a separate path. The decomposition of sunlight by refraction is shown in various familiar phenomena; the rainbow, the play of colour in the diamond and in the facets of cut glass, and the glow of colour upon the landscape in the light of the rising and setting sun,†—all these effects are occasioned by the decomposition of white light by refraction.

The colours of the solar spectrum possess a purity and brilliancy ‡ to be met with nowhere else; they are all perfectly indivisible, and cannot be further decomposed, but they lie so thickly together that even the smallest pencil of rays that can be taken from the spectrum behaves as if consisting of a great number of rays, and in fact contains varying shades of the colour selected. This may be easily proved by analysing any of the rays of the spectrum by a second prism. If a small round hole is made in the screen in any portion of the image of the spectrum,—the extreme red, for instance (Fig. 26),—a red ray passes through it, and appears upon the opposite wall as a spot of red light. By the second prism the ray will suffer a second deviation, and the image be thrown higher up on the wall. This new image, however, is not circular, but somewhat elongated, showing that the red ray coming through the small

* [It is often convenient to subdivide the colours into more than seven. Professor Piazzi Smyth's subdivision is as follows: crimson-red, red, scarlet, orange, amber, yellow, citron, green, glaucous, blue, indigo, violet, lavender.]

† [Sunset and sunrise glows are not so easily explained.]

‡ [Brilliancy, yes, but scarcely the case as regards purity.]

hole is not of one single tint of red, but is composed of several rays of various shades of red. This applies, without exception, to all the colours of the spectrum, a proof that the colours of the spectrum produced by a prism may be yet further separated by the action of a second prism.

17. The Dispersion of Light.

The decomposition of white light into its coloured rays is called the *dispersion* of light. In this process of decomposition the further apart the extreme outside rays are separated, the greater is the amount of dispersion. In the decomposition of white solar light, the red and violet rays form the boundaries of the visible spectrum, for the rays least deflected from the angle of incidence are the red, and those most deflected are the violet. The difference between these two angles is a measure of the amount of dispersion.

As the amount of deviation is in proportion to the size of the refracting angle of the prism, so the amount of dispersion varies in prisms of the same substance according to the size of this angle. Thus spectra produced by such prisms will vary in length according to the largeness of the refracting angle, but in every variation in the length of the spectrum the space occupied by each colour will retain its due proportion. If the spectrum is doubled in length, each band of colour will be doubled also.

We have already observed that in the same substance a variation of structure—as, for example, in glass of different densities—has a great influence upon the index of refraction, and, in consequence, upon the deviation of the rays. Prisms of the same refracting angle, but constructed of glass of varying density, differ in the amount of deviation given to each colour, and the spectra produced by

such prisms differ not only in length as a whole, but in the space occupied by each colour.*

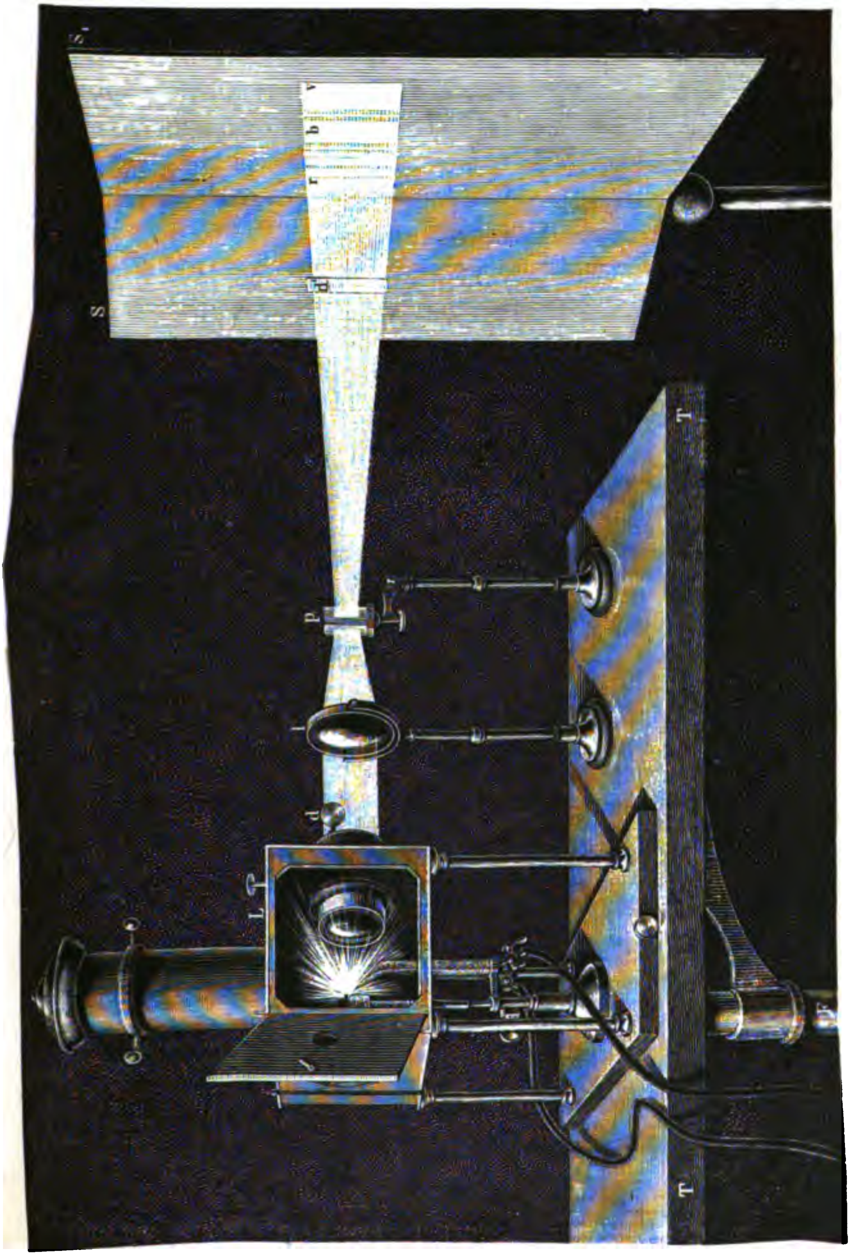
18. The Spectra of the Lime-light and the Electric Light.

In the absence of sunlight, the Drummond lime-light forms a good substitute, and its spectrum may be exhibited to an audience in the following manner. Let the lantern L (Fig. 27), already described, be placed on a table T T, 5 feet long and 16 inches wide, turning on a pedestal F, and in front of the lamp insert the diaphragm *d*, which confines the light to a narrow slit. Opposite the lantern, at a distance of 12 or 15 feet, place two paper screens S S_1, 8 feet square, very slightly inclined to one another; let the lime cylinders then be raised to incandescence by means of the oxyhydrogen jet, the room be darkened, and the table T T so turned that the tube *d* of the lantern is perpendicular to one of the screens (S). Then let a double convex lens *l*, of 4 inches diameter, and about 12 inches focus, be placed between the slit *d* and the screen S, at a distance of about 12 inches from the slit, so as to throw the rays issuing from the slit upon the screen S in the form of a sharp and magnified image, d^1, of the slit *d*. Close behind this lens *l*, a flint-glass prism P of 60°, 2½ inches high and 2 inches broad, must be placed in the direct path of the rays,† when there will appear on the second screen S_1 a magnificent spectrum, about 3 feet long and 16 inches wide, exhibiting the whole range of colours as shown in Plate XIV., No. 1. Owing to the distance of the screen, the spectrum is very considerably displaced from the spot d^1,

* See Appendix B.

† This position of the prism is the most advantageous, because the loss of light is least; the spectrum would be nearly as good if the prism were moved 11 or 12 inches from the lens.

Fig. 27.



Projection of the Spectrum of the Lime-Light.

where the rays fell when undeflected by the prism; the red lies nearest to that straight line, the violet is the furthest removed from it; the former is therefore the least refracted, and the latter the most so. The individual colours succeed each other without interruption; their limits are not sharply defined, but they blend one into the other, and thus form an unbroken or *continuous* spectrum.

In order to obtain a pure spectrum, the width of the slit ought not to exceed one-sixteenth of an inch; were it wider, the spectrum would greatly increase in splendour

Fig. 28.

Prism of Bisulphide of Carbon.

and brilliancy, but the central colours would lose in purity, and no longer be so clearly separated.

In many instances a *transparent* screen may be advantageously used, behind which the lamp is placed. The screen is then visible without interruption from the lantern or experimenter, and the whole arrangement is much simplified.

The spectrum of the electric light may be exhibited in a similar manner by substituting an electric lamp for the oxyhydrogen lamp, and properly connecting the carbon points with an electric battery of 50 Bunsen's or Grove's large cells. The slit may be somewhat contracted to secure the maximum purity of the spectrum. With a wider slit

the spectrum gains in brilliancy, but remains sufficiently pure to allow of its being increased to double or treble the length of that of the lime-light. To effect this prisms of some highly refractive substance, such as dense flint glass, with a refracting angle not less than from 45° to 60°, must be employed. If still greater refractive power is required, liquid bisulphide of carbon may be employed by enclosing it in a hollow prism (Fig. 28), composed of pieces of plane plate glass cemented together. The surfaces of the plates being parallel, the rays of light suffer no deviation in passing through the glass, nor does the glass exercise any influence on the course of the rays through the liquid.

We have already noticed that light, after having been dispersed by one prism, may yet suffer a further dispersion by the interposition of a second prism. If immediately behind a prism of flint glass, a second prism of flint glass or of bisulphide of carbon is introduced, and so arranged as to throw the rays upon the second prism in a manner similar to that in which it itself had received the light from the lens (the prisms forming an angle of about 100° with each other); a spectrum will be obtained of about eight feet in length, and deflected more than 90° from the original direction of the beam: the colours, though still clearly visible, and easily distinguishable one from another, will, however, have lost much of their original brilliancy. A combination of two bisulphide of carbon prisms, placed at an angle of 110°, would lengthen the spectrum still further, but the brightness would be diminished proportionally to the increased length.

19. Recombination of the Colours of the Spectrum.

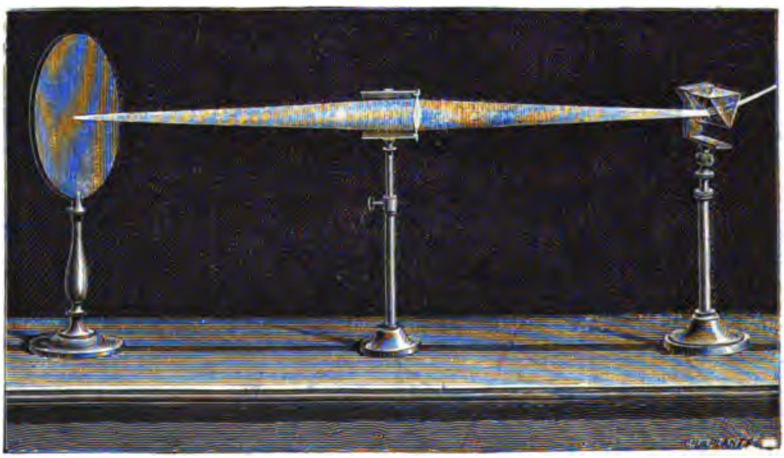
If white light is composed of the colours of the spectrum, then the recombination of the colours ought to reproduce

white light. This may be demonstrated by means of the spectrum of the electric light when thrown upon a screen. If a cylindrical lens (Fig. 29) is interposed between the prism and the screen so as to receive all the coloured rays, they will converge, and the narrow line of light formed at the focus will be white.

20. Influence of the Width of Slit on the Purity of the Spectrum.

For the purity of a spectrum it is necessary that the

Fig. 29.

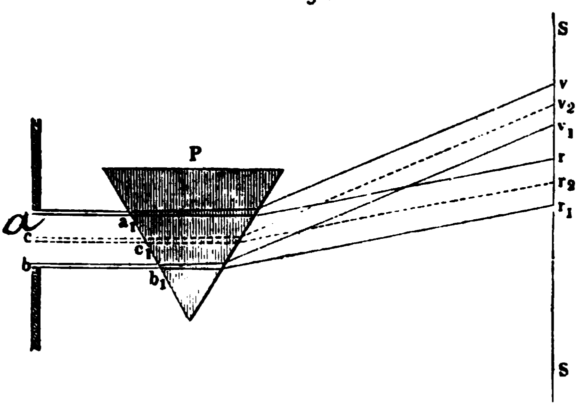


Recombination of the Colours of the Spectrum.

coloured rays belonging to each white ray should, after their separation by the prism, reach the eye unmixed and unimpeded. If, as in Newton's experiment, a ray of white light is allowed to enter a darkened room through a small *round* hole and intercepted by a prism, the spectrum produced will be obviously far from pure. In Fig. 30 let *a b* represent a horizontal opening in front of the prism P, the refracting edge of which is supposed to be horizontal. A horizontal ray of white light *a* a_1, grazing the extreme end *a* of the

opening $a\ b$, and falling on to the prism, produces a complete spectrum of its own $r\ v$, which in the plane of incidence between r and v—or the red and the violet—contains all the colours of the spectrum. In the same manner the ray $b\ b_1$ grazing from the other end of the opening b produces likewise a complete spectrum of its own, containing every colour. Between a and b are an indefinite number of points through which light passes, the number of which increase according to the width of the slit; out of these let us select for consideration the point c, the ray from which $c\ c_1$ forms

FIG. 30.



Influence of the Width of Slit on the Purity of the Spectrum.

another spectrum $r_2\ v_2$ between the two outer spectra, $r\ v$ and $r_1\ v_1$, which it is evident falls partly over the two other spectra between the two points $r_2\ v_2$. While in the portions $v\ v_2$, $r_2\ r_1$ there are parts of the pure spectra formed by the rays $a\ a_1$ and $b\ b_1$, there are to be found in the portions $v_2\ r_2$ of the compound spectra $v\ r_1$ the superposed colours due to the whole slit, and their colours, being no longer separately distinguishable, produce the impression of a confusion of tints. The spectrum of white light, tnerefore, emitted through a wide slit is only pure or of unmixed

colour at the extreme ends, viz., in the red and in the violet rays; in the middle there is mixed light in an extreme case, composed of all possible groups of rays.

Newton was never able therefore to produce a pure solar spectrum, because the round hole through which he admitted the light was too wide for its production. It was not till 1802 that the round hole was superseded by the slit. The idea occurred to Wollaston that if instead of a round hole a narrow opening with sides parallel to the refracting edge of the prism were employed, the effect would be that every point in the thin line of light would produce a complete and pure spectrum. The result of this would be that a series of pure spectra would be formed which in their entirety would appear as one broad and pure spectrum. Experiment justified his conception, and he thus obtained a solar spectrum of unprecedented purity. Since his day nearly all investigations of the spectrum have been conducted by admitting the light through a narrow slit formed, as a rule, by two metal plates, regulated by a screw so that the width of opening can be controlled.

The mechanism for regulating the slit is mostly of a simple kind; in special cases a micrometer is attached for the accurate measurement of the width of opening employed.

The purity of the spectrum depends not only upon the width of the slit, but upon the sharpness and cleanness of its edges. Particles of dust clinging to the walls of the slit suffice to create dark streaks along the whole length of the spectrum, which much impede observation.

Should such streaks make their appearance, the slit ought to be carefully wiped from dust with a camel's hair pencil.*

* [This is scarcely sufficient. It is better to cut a fine wedge of hard wood and insert it between the jaws of the slit, and by a gentle upward and downward motion to get rid of the adhering particles.]

It is scarcely necessary to remark that the slit must always be guarded with the greatest care from rust, or from the action of salts and vapours. Brass is perhaps the least satisfactory material that can be used, but steel has been employed with good effect, while a further improvement has been the introduction of an alloy of gold, which, while easy to work, is impervious to rust and changes of temperature. Rutherford, of New York, has adopted obsidian, which is capable of resisting chemical action, and with careful usage remains unaffected by wear. A suitable material has also been found in a very hard platinum alloy, such as was adopted for the French standard metre.

21. The Fraunhofer Lines in the Solar Spectrum.

When Wollaston, in 1802, was looking casually through a prism at a narrow opening in a window blind, he observed that the spectrum was throughout crossed by a great number of dark lines, all parallel to the slit. He neglected, however, to follow up this discovery, and it was not until 1814 that Fraunhofer, the celebrated German optician, recognizing the importance of the phenomenon, set himself to determine the positions of the most prominent of these lines. These dark lines show that though the sun may send out rays of every kind and of every colour, yet the whole of these rays are not received by us, but that certain coloured rays, or rather rays of a certain refrangibility, are extinguished. The cause of these dark lines was not discovered till long after, but Fraunhofer succeeded in mapping about six hundred such lines. He observed, moreover, that with the same prism and telescope the lines always kept the same order and relative position, and were therefore admirably fitted for the identification of individual coloured rays, or for the determination of their refrangibility.

Fig. 31.- Fraunhofer's Solar Spectrum.

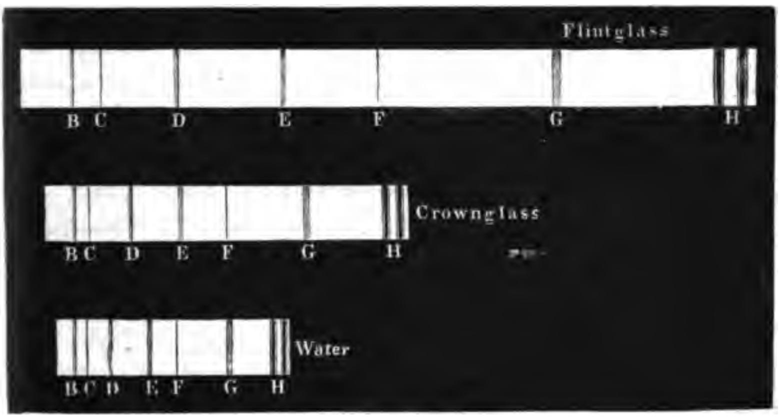
To facilitate reference to any portion of the solar spectrum (Plate XIV., Nos. 1, 9, 10), Fraunhofer, whose drawing is given in Fig. 31, designated *eight* of the most prominent lines by the letters A, B, C, D, E, F, G, H; of these lines A and B lie in the red, C in the red near the orange, D in the orange, forming a double line with a high power, E in the yellow, F on the borders of the green and blue, G in the dark blue or indigo, and H in the violet. Besides these lines, there is a noticeable group *a* of fine lines between A and B, and also a group *b*, consisting of three fine lines,* between E and F. It may here be remarked that Fraunhofer found that the position of the two dark lines in the solar-spectrum, designated by him D were coincident with the two bright lines, now known as the double sodium line, shown by the light of a lamp. The whole of the dark lines of the solar spectrum have been called, after their discoverer, the Fraunhofer lines.

In forming the spectrum, if instead of a prism of crown glass one of flint glass is employed, the dispersion of the light will be greater and the length of the spectrum increased. In consequence of this extension the

* [Better marked even than E in the present state of the solar spectrum.]

separation between the Fraunhofer lines increases also, but by no means proportionally. Fig. 32 exhibits the various dispersive powers of flint-glass, crown-glass, and water. If the spectrum of the flint-glass prism was exactly twice the length of that of the crown-glass prism, the distance between any two dark lines, F and B for instance, will not be exactly twice as great in the one spectrum as in the other. The crown-glass spectrum is longer than the water spectrum, but the various divisions formed by the Fraunhofer lines

Fig. 32.



Solar Spectrum with Prisms of Flint-Glass, Crown-Glass, and Water.

have not increased in equal proportions. In the water spectrum F B = F H, while in the crown-glass spectrum F B is somewhat smaller than F H; by the latter prism, therefore, the blue and violet end is rather further extended in comparison with the red and yellow end than by the water prism.

This difference is still more obvious in comparing the two spectra formed by the water and the flint-glass prisms with an equal deviation of the light corresponding to the line B; the difference in the proportion of F B to F H is smaller

in the flint-glass spectrum than in the water spectrum, and this difference is more apparent than in the crown-glass spectrum.

It would be, therefore, an error to take for granted that the distances between individual dark lines in the spectrum* change in exactly the same proportion as the entire length of the spectrum. Even if the dispersive power of a substance is known for the extreme rays, or for the lines B and H, the amount of separation between the intervening lines of the spectrum cannot be deduced from it; the relative position of these lines must be specially ascertained for each refracting substance. An accurate knowledge of the particular conditions of the spectrum apparatus employed must therefore be acquired by every observer before any value can be given to the results of observations made with it; he must become familiar with the precise places of all the chief lines and groups of lines seen in the solar spectrum, so that in the examination of any particular line, whether in the spectrum of a terrestrial substance or of a heavenly body, he may know, at least approximately, to which Fraunhofer line it lies nearest.

22. Indices of Refraction and Amount of Dispersion for the most Prominent Fraunhofer Lines.

Before the discovery of the Fraunhofer lines, the indices of refraction for the various coloured rays could only be approximately ascertained by estimations from the yellow—the central portion—of the spectrum; but at present the dark lines afford an easy means of determining the index of refraction for every part in the spectrum. Many of these measures were made with great exactness by Fraunhofer,

* [When the prisms are formed of different materials.]

but since his day more refined researches have been carried out by many other physicists.

In Appendix C will be found a table giving the index of refraction for several substances, both solid and liquid, as measured by the chief Fraunhofer lines.

23. The Continuous Spectra of Solid and Liquid Bodies.

When the carbon points used for the production of the electric light are carefully prepared, and completely free from all extraneous substances, the light is purely white. The spectrum of this light is, therefore, continuous, unbroken by gaps or by sudden transitions from one colour to another, and is uninterrupted by either dark or bright bands.*

All solid or liquid incandescent bodies give similar spectra, the colours being distributed in the order represented in Plate XIV., No. 1, with this difference—that the various groups of colour are not always distributed in exactly the same proportion, and therefore some one tint predominates.

It is only in very rare instances that incandescent solid substances emit an isolated set of coloured rays with any pre-eminent strength, though such seems to be the case with the very rare substance Erbia. It may therefore be considered that, as a rule, where there is *a continuous spectrum without gaps, aud containing every shade of colour, the light is derived from an incandescent solid or liquid body.*

This important law was first announced in 1847 by Professor J. W. Draper, of New York. He laid down the

* [It is impossible as yet to get carbons perfectly free from impurities, and the continuity of the spectrum is much marred by the bands of lines due to carbon vapour.]

following propositions—that all solid and probably also all liquid bodies become incandescent at the same temperature, and are of a red heat at about 525° C.; that the spectrum of an incandescent solid body is continuous, interrupted neither by bright nor dark lines; that the rays given out by a substance at any ordinary temperature or up to 525° C. make no sensible impression upon the eye; that all substances at that temperature begin to give out visible rays, at first rays only of a dark red, to which are constantly added, as the temperature rises, new rays of increasing refrangibility, the united effect of which is a continual increase in brilliancy.

Kirchhoff has since expressed this proposition in similar terms, as follows:—"When any substance—as, for instance, a piece of platinum wire—is heated gradually, it emits up to a certain temperature rays of a wave-length greater than any visible ray. At a certain temperature rays of a wave-length, answering to extreme red, begin to show themselves; as the temperature increases rays of shorter wave-length are added, so that for every advance in temperature there is an addition of rays of a corresponding wave-length, while at the same time the rays of greater wave-length gain in intensity. . . . . The *intensity* of the rays of certain wave-lengths given out at the same temperature by different substances may however differ very considerably."

An acquaintance with the laws of the *emission* of light is of the highest importance in spectrum analysis; for if rightly interpreted, the light emitted by any substance reveals not only the nature of the substance, but also its temperature.

24. The Spectra of Vapours and Gases.

A spectrum of a different kind is obtained if the source of light is a *vapour* or a *gas* in a glowing state. Instead of a continuous and blended succession of colours, the spectrum consists of a series of distinct bright-coloured bands, separated one from another by dark spaces.

As gases and vapours in a luminous state emit much less light than solid bodies, the exhibition of these spectra before a large audience is restricted to those of greatest brilliancy—such as are yielded by the vapours of copper, zinc, brass, silver, cadmium, sodium, thallium, etc.

Although the oxyhydrogen flame, from its feeble luminosity, is suitable for these experiments, yet the electric lamp is better adapted to the purpose, as in the greater heat of the latter substances are more readily volatilized, and are also brought to a higher state of luminosity. For the exhibition of these spectra, the apparatus described in § 18 and drawn p53 in Fig. 27 is employed. The lower carbon pole of the lamp is replaced by a half-inch cylinder of pure carbon, the upper end of which is slightly hollowed, and fixed in the focus of the lantern lens. In this hollow is laid a piece of zinc the size of a pea, and the upper pole is brought down in contact with it, when the electric current instantly volatilizes the zinc. If the upper carbon pole is now so far withdrawn as to allow the zinc vapour to form an arc of flame, not the spectrum of incandescent zinc, but that of its vapour, will be seen on the screen. This spectrum differs essentially from the continuous spectrum already described; it broadly consists only of one red and three very beautiful bright blue bands.

If the carbon contaminated by the zinc is replaced by a fresh cylinder, in the cavity of which is placed a piece of copper, the spectrum will be found to consist of three

bright bands in the green. If the same experiment is made with brass (an alloy of zinc and copper), the spectrum will be a compound one, consisting of the superposed spectra of the two metals.

Fig. 33.

Ruhmkorff's Electric Lamp.

To avoid changing the lower carbon cylinder a lamp has been contrived by Ruhmkorff, shown in Fig. 33, in which six carbon cylinders are arranged in a circle upon a small plate revolving upon the carrier G, in such a manner that any one of them may be brought under the carbon cylinder *o*. This cylinder can be adjusted by the screw *b*, and the whole of the lamp raised or lowered by the screw *a*.

Very beautiful and characteristic spectra may be similarly obtained from silver and thallium. If, however, both these metals are placed upon the carbon at the same time and volatilized, the two lines in the green of the silver are overpowered by the intenser green line of the thallium, which lies between them, and these only recover their full intensity after the thallium lines have disappeared. This is due to the different resistance encountered by the current in passing from one carbon to the other. The greater it is, the higher is the temperature of the arc: when the resistance is small the heat produced is not great. The

thallium melting at a low temperature is quickly volatilized, and the presence of the vapour immediately lessens the resistance in the arc, and consequently lowers the temperature to such an extent that the silver is not volatilized. When the thallium is nearly burnt out, the resistance to the current rapidly increases, and the temperature is thereby so considerably raised that the silver becomes volatilized.

The characteristic feature of spectra obtained from luminous vapours or gases is the want of continuity in the succession of the colours. Such a spectrum being composed of isolated coloured bands, irregularly arranged, and separated by dark spaces, is therefore called a ***discontinuous spectrum***, a ***bright line spectrum***, or a ***vapour spectrum***.

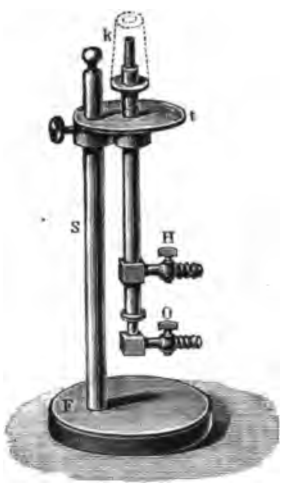
In the coloured plate (Plate XIV.), Nos. 2, 3, 4, and 5 give the spectra of the vapours of sodium, magnesium, chloride of strontium, and hydrogen under great pressure. No. 6 gives the spectrum of the vapour of hydrogen under a low pressure. They exhibit at a glance the great difference that exists between the continuous spectrum (No. 1) of incandescent solid and liquid bodies and the discontinuous spectra of gases. The vapour of sodium (No. 2) under ordinary circumstances, and when not exposed to an extremely high temperature, gives a spectrum consisting only of one bright orange line shown to be double by the use of sufficient dispersive power.* The spectrum of luminous magnesium vapour (No. 3) consists of very brilliant isolated green and blue lines; but the spectrum of chloride of strontium is much more complete, and it may serve as an example of the spectrum of a compound substance. The fine lines in the blue green belong solely to the metal strontium, the broad stripes or channelled spaces to the compound substance, chloride of strontium.

We have seen in the case of brass that when two metals

* [There are two other lines in the infra red of the spectrum.]

are in combination the spectrum yielded is a compound one, consisting of that of each metal superposed. But this is not the case when a metal is in combination with a non-metallic substance such as common salt, a compound of chlorine and sodium. If salt is volatilized, the spectrum obtained is merely that of sodium, in which no trace appears of the characteristic spectrum of chlorine. The spectra of the vapours of metals invariably overpower that of any non-metallic substance with which they may be in combination, but where several metals are volatilized at the same time, the spectrum of each metal asserts itself, and can be recognised in the compound spectrum produced.

FIG. 34.



Edelmann's Oxyhydrogen Gas-Lamp.

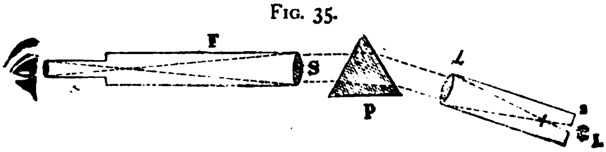
It has recently been ascertained that the spectra of metals can be produced at a much lower temperature if the metals are first reduced to the form of metallic salts. In this condition an oxyhydrogen gas flame is sufficient for the purpose. The lamp devised by Edelmann, who was the first to employ this method, is given in Fig. 34. It consists of a vertical double tube, the outer one H for the supply of ordinary gas, the inner one O for the supply of oxygen. By the disc *t* this double tube is attached to the iron pillar S, which can be raised or lowered at pleasure. On the end of the tubes is fixed a nozzle *k* for the reception of a hollow cone of charcoal, the inside of which is smeared with a paste composed of the salts of the metal to be observed, rubbed down smooth in a mortar, and mixed with picric acid, ammonia,

and alcohol. It will be necessary to prepare as many of such carbons as there are spectra to be exhibited. The lamp is so constructed as to fit into the lantern shown in Fig. 12, which allows of the flame being placed in the focus of the lenses. The same care must be taken in lighting the flame as with the ordinary oxyhydrogen lamp described in § 4.

25. The Simple Spectroscope.

Every spectrum apparatus or spectroscope, exclusive of the source of light, is composed of an adjustable slit, a collimating lens for rendering the rays parallel that have passed through the slit, and a prism. In order to exclude all light from the prism—all light except that under examination—the slit,

Fig. 35.



The Simple Spectroscope.

lenses, and prism are enclosed in a tube, or if the prism be too large, the latter is fitted with a separate cover. Such an arrangement is shown in Fig. 35. As the spectrum on emerging from the prism is too small for examination, it is viewed through a telescope of moderate power.

It has been already mentioned that the coloured rays composing the spectrum form an angle with the incident rays as they enter the prism. It is therefore necessary, in observing the spectrum, that the tube of the telescope directed to the outer surface of the prism should be placed in a different direction from the tube carrying the slit and the lens. The light emitted from L, after passing through the slit *s* and the collimating lens *l*, reaches the prism *p* in parallel rays;

it is there refracted as well as decomposed, whereby the spectrum S is seen through the telescope F in a direction different from that of the tube *s l*.

The prism in a spectroscope is usually so arranged that the brightest rays in the yellow have the minimum deviation. Should this not be the case, a readjustment may be accomplished in the following manner. Let the telescope F (Fig. ~~37~~) first be so placed that the observer can see distinctly a very distant object—a fixed star, for instance; then let it be attached to the apparatus in such a manner that its axis shall be parallel to that of the tube *l s* carrying the slit. The prism *p* should now be removed, and the slit *s* examined through the telescope. If the edges of the slit do not appear sharp, the tube carrying the slit plate *s* must be pushed in or out of the collimator tube *l* until they become well defined.* The prism must then be placed between the tubes at such an inclination as that the refracting edge is perpendicular to the axis common to both tubes; the length of the slit must also lie in the same direction. Finally the prism must be so placed that the parallel rays falling upon it from the collimating lens strike the whole surface of the prism at the angle of minimum deviation of the central yellow

* [This method of adjusting the telescope and collimator answers fairly well when great delicacy of adjustment is not required. It has already been stated that different coloured rays are differently refracted; hence the collimating lens by the above adjustment will not make all the rays parallel. They will only be strictly parallel for one or two colours, the latter being the case when the lens is achromatized by a combination of two lenses of different materials—such as one of flint and the other of crown glass. For accurate definition the collimator should be focussed for each ray, and the telescope then focussed in the ordinary manner. Mr. Grubb, of Dublin, has introduced a form of spectroscope in which the telescope objective and that of the collimator are of equal focal length, and an alteration in the focus of the telescope also *automatically* alters the focus of the collimator.]

ray *—the light of sodium, for instance, a position which with a little practice may be easily secured by the twisting of the prism and the telescope.

26. The Direct-vision Spectroscope.

In the arrangement just described, it is not easy at once to find the spectrum, as the eye cannot be directed straight at the light. It would therefore be more convenient if the slit, lens, prism, and telescope were all in a straight line, so that the instrument could be directed like a telescope to the light to be examined, and the spectrum observed.

Fig. 36.

Neutralization of Refraction and Dispersion.

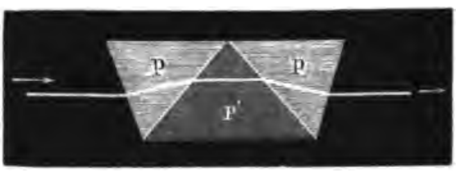
If two prisms A and B (Fig. 36), of similar composition and equal refracting angle, are placed in reversed positions, the incident ray E, of white light, will be refracted by the first prism A, and decomposed into its coloured rays; the

* [The green ray is often taken instead of the yellow ray. We may remark, however, that there is no special reason to place the prism at the angle of minimum deviation when a collimating lens is used; that was necessary in the early methods of forming spectra. It frequently happens that the definition of a prism is better when some other ray is chosen for minimum deviation.]

second prism B, however, which refracts in an opposite direction, destroys the first deviation, and reunites the incident coloured rays into a single emergent ray F. If the ray F is received upon a screen, a white image, tinged at the upper edge with red, and at the lower with violet light, will be seen, because at the extreme edges of the image the colours are not superposed. In this case the second prism B has neutralized both the deviation and the *dispersion* of the first prism, and the action of this system of prisms is very nearly the same as that of a thick piece of glass with parallel sides.

Now if the dispersive power of a prism varied in the same

FIG. 37.



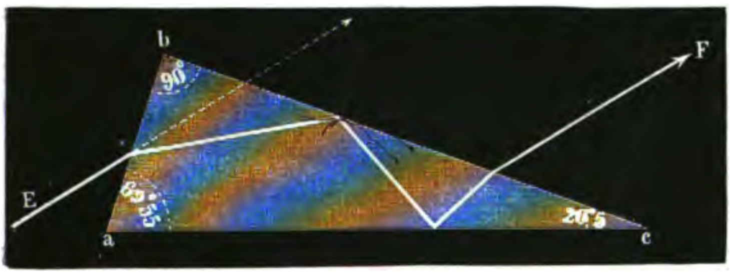
Amici's Direct-vision System of Prisms.

proportion as its power of refraction, then whatever the kind of glass employed for the prisms placed as in Fig. 36, and whatever their refracting angles, when they were so placed as to neutralize deviation, their dispersion and consequent capability of forming a spectrum would be also destroyed. In other words, the formation of a spectrum would always be connected with the deviation of light from its incident course, and it would not be possible by means of any system of prisms to receive the spectrum of a luminous object—for example, a flame or a star—in a straight line.

In reality, however, this is not the case. The dispersive power of various kinds of prisms is not, as we have seen in § 20, in equal proportion to the refractive power; a flint-glass prism, for instance, gives with an equal amount of deviation

of the central rays a spectrum of much greater length than can be obtained from one of crown glass. It is therefore possible so to combine two prisms of different refracting angles, one of flint and the other of crown glass, that the deviation of the incident rays shall be entirely eliminated, while the greater dispersive power of the flint glass only partially destroys that of the crown glass, and consequently a spectrum is formed by the remaining rays. If a bright object is viewed directly through such a system of prisms, its spectrum will be seen in the line of sight; the colours will not be so widely dispersed, nor will the spectrum be

FIG. 38.



Herschel's Direct-vision Prism.

so long as would be the case were the object looked at in an oblique direction through the flint-glass prism alone.

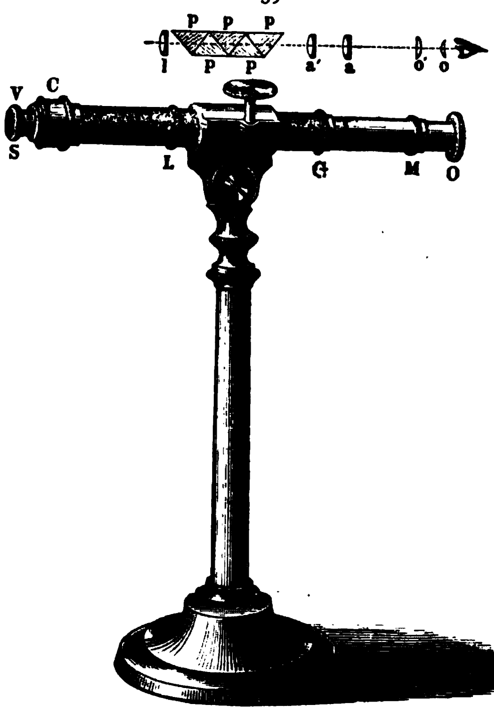
Compound prisms of this kind, or more especially systems of prisms which show a spectrum when held in a straight line between the source of light and the observer's eye, are called ***direct-vision*** prisms.

Such an arrangement of the spectroscope was approximately accomplished by Amici, in 1860 (Fig. 37), by a judicious combination of two crown-glass prisms with a third prism of flint glass of 90° interposed. By this construction the rays of mean refrangibility suffer no deviation, so that a luminous object may be directly viewed, and a spectrum

obtained, since the dispersion produced by the flint-glass prism in one direction is greater than that produced by the two crown-glass prisms in the opposite direction.

Fig. 38 exhibits another form of direct-vision prism, contrived by Professor A. Herschel for the observation of

FIG. 39.



Janssen-Hofmann's Direct-vision Spectroscope.

meteors. The ray of light E undergoes two total reflections from the inner surfaces of the prism before it emerges from it in the form of the spectrum F, in a direction parallel to E. Upon the same principle other compound prisms have been devised, but great difficulties attend their construction, as every surface is in action, and extreme accuracy is required in the angles *a* and *c*.

Janssen, by adopting Amici's construction, has produced a direct-vision spectroscope, yielding spectra of great length and purity. It has the appearance of an ordinary telescope (Fig. 39), and can either be held in the hand or placed upon a small revolving stand. The optical parts are shown in the drawing above the instrument, in the same positions that they occupy within the tube. In the front, which is directed towards the source of light, is the slit S, formed of two steel edges, which can be easily widened or contracted by means of the screw V and an opposing spring. At L the collimating lens *l* is inserted, by which the rays diverging from the slit S are rendered parallel, and thrown upon

FIG. 40.

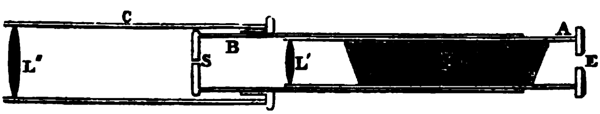
Janssen's Direct-vision System of Prisms.

the five prisms *p*. Of these, which are drawn in detail in Fig. 40, the first, third, and fifth are of crown glass, while the second and fourth are of flint glass, and they form so perfect a system from the accurate adjustment of the angles of the prisms, that the emergent central coloured rays F have precisely the same direction as the incident rays E, and therefore pass in a straight line through the tube L G M O, in which the compound prisms occupy the space between L and G. The lenses *a'* and *a* behind G form the object-glass; *o'* and *o* in the small sliding tube O, the eyepiece of the telescope through which the spectrum is observed. Larger spectroscopes on the same principle are now much in use.

[A very convenient form of direct-vision spectroscope is

shown in Fig. 41, where the compound prism, such as Fig. 40, is enclosed in a tube A which is terminated at the end by a lens L′, and at the other by an opening E at which the eye is placed. The tube A slides into a second tube B, which carries an adjustable slit S. So far this constitutes the ordinary form of pocket spectroscope, the spectroscope being directed towards any luminous source, and focus is obtained by sliding the tube A in tube B till the Fraunhofer lines, or other bright vapour lines, such as sodium, are seen sharply defined when the slit is narrowed. A capital addition to such a spectroscope is another slide tube C, carrying a lens L″ of short focus, which is so adjusted as to throw the image of any object on the slit S. By this

Fig. 41.



Convenient Form of Pocket Spectroscope.

means the light from any coloured object, or from different parts of a cloud, for instance, can be examined; whereas in the ordinary form merely the general light coming in any particular direction is examined. Any spectroscope where this addition is made, the spectroscope is usually called an *analysing* spectroscope; the usual form is called an *integrating* spectroscope.]

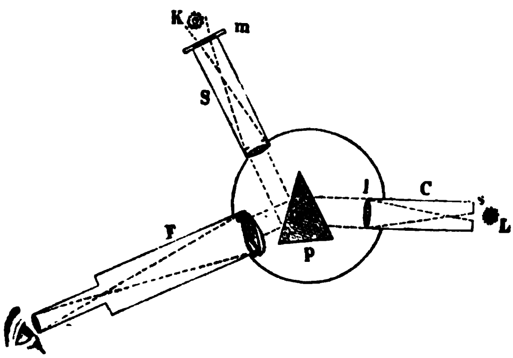
27. Mode of Measuring the Distances between the Lines of the Spectrum.

The exact position and relative distances of the lines of a spectrum are data of the utmost importance, since on them depends the identification of spectra, and in some instances some lines of one spectrum approach so near to

those of another that the greatest precision of measurement is necessary for determining to which spectrum they belong.

Under similar conditions the number and relative position of the spectrum lines of a substance are invariably the same, but their *apparent* position varies with any change in the details of the spectrum apparatus—whether it be in the refracting angle of the prisms, their dispersive power, or even the size of the telescope. On this account it is requisite to have some means of measuring the distance of the individual lines one from the other, and of determining their relative positions.

FIG. 42.



Graduated Scale in Spectroscope.

The simplest method of accomplishing this is by the addition of a third tube S (Fig. 42) carrying a millimetre scale *m*, photographed on glass, the image of which by means of the light K is thrown upon the prism surface at *n*, whence it is reflected through the axis of the telescope F, and is seen simultaneously with the spectrum to be observed. The reading of the scale is facilitated by adjusting the scale *m* so as to bring one of the divisions—for instance, 100—into coincidence with any of the Fraunhofer lines. As the divisions are arbitrary, the measures can only

be compared with one another when the value of the divisions has been determined by a comparison with the Fraunhofer lines as seen in the same instrument. It will readily be understood that only a small portion of the spectrum can be clearly seen at the same time with the divisions of the scale.

Under ordinary circumstances the spectroscope is not often required to determine the absolute position of any line in the spectrum; but it is very necessary to have an easy method of ascertaining its relative position with regard to any other known line. For this purpose the arrangement just described is all that can be desired, and it is not only applicable to large instruments, but to even the smallest miniature spectroscope.

When the spectrum to be examined is faint, as in the case of a star, and the lines are in danger of being overpowered by the comparatively bright lines of the scale, a black paper millimetre scale may be substituted with the divisions marked in white. If this is illuminated by a side lamp screened from the spectroscope, the pale image of the scale is seen projected on to the spectrum. If the investigation is directed to a single line or to two close faint lines, the scale, whether of glass or of paper, should be partially covered, so as to allow only that portion of the image to reach the eye-piece which lies over the part under observation.

In the well-known tables of the spectra of terrestrial substances constructed by Kirchhoff and Bunsen, an arbitrary scale was employed in which the value of the Fraunhofer lines was as follows:—

A = 17·5	G = 75·7
B = 28·0	F = 89·6
C = 34·0	G = 127·5
D = 50·0	H = 161·8
E = 71·0	H_1 = 166·0

A contrivance preferable to any scale is that by which a sharply-defined mark is made to travel along the spectrum, and the amount of motion measured by a micrometer. This consists of a sliding plate *a* (Fig. 43), provided with a slit or fine metal wire, travelling on an underplate *b b*, the motion being regulated by an exceedingly fine screw *d*, the head *c* of which is engraved as in a divided circle. In order to measure the amount of motion, the value of a screw-thread must be ascertained, and the screw-head *c* be so divided as to mark off parts of an entire revolution. If, for instance, one revolution of the screw is half a millimetre in value, and the circumference of the screw-head *c* is

FIG. 43.

Micrometer for Measuring the Distances between the Lines.

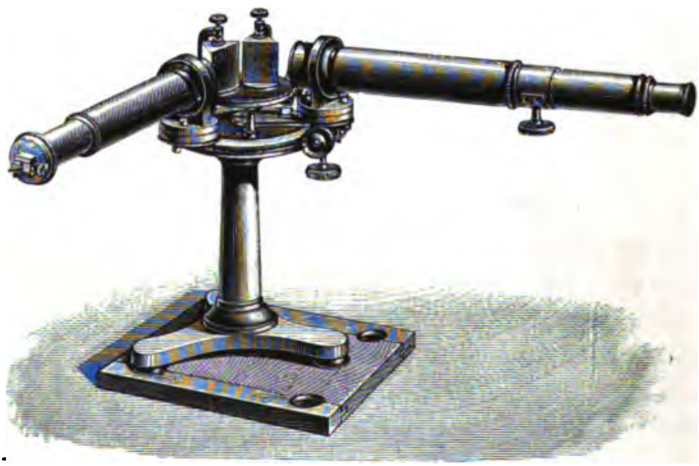
divided into fifty equal parts, the displacement of the mark by a complete revolution of the screw amounts to half a millimetre; consequently a displacement amounting to one division of the screw-head is equivalent to $\frac{1}{100}$ of a millimetre. Parts of a revolution are read off at *n*, while the complete revolutions are registered by the indicator on the slide *a*.

A third method of measurement consists in giving a motion to the slit, by which the spectrum is moved in front of a fixed mark.

Another method frequently adopted is by registering the radial motion of a telescope, furnished with a mark such as cross-wires or a line of light. A spectroscope of this

construction is shown in Fig. 44. The collimator tube (to the left) is fixed; the observing telescope with the cross-wires travels upon an arc round the divided circle, so that it can be directed upon any portion of the spectrum, and the angular displacement read off. In this way the distance of one line from another is measured in degrees and minutes by the angle of their separation. For any given instrument it is easy to calculate the

FIG. 44.



Spectroscope with two Prisms for Measuring the Distances between the Lines.

distance between the lines from the angles measured; and when comparisons are required with other instruments, the true values may be found by comparing the readings of the instrument with the true position of the Fraunhofer lines.

In many instances the employment of dark measuring marks, such as cross-wires, or glass, or metallic grating, is inconvenient, as from their want of light they do not sufficiently stand out from the spectrum; and when arti-

ficially illuminated, their brightness interferes with the brightness of the spectrum. A line of light is much more efficient, as its intensity can be regulated according to the degree of brightness of the lines to be measured. Such a line is ingeniously furnished by the arrangement sketched in Fig. 45, the chief feature of which is the small glass plate P (Fig. 45*a*), which is about 0·4 inch in width, and less than $\frac{1}{30}$ inch in thickness, and the underside of which is sloped off at an angle of 45°. With the exception of the upper surface, the plate is made impervious to light by

FIG. 45 *a*.

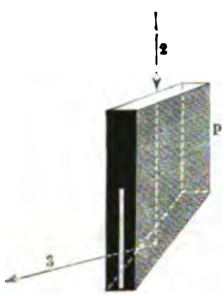
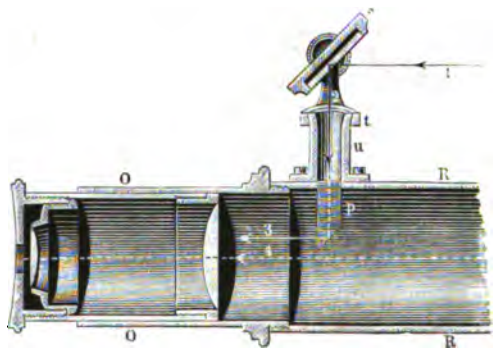


FIG. 45 *b*.



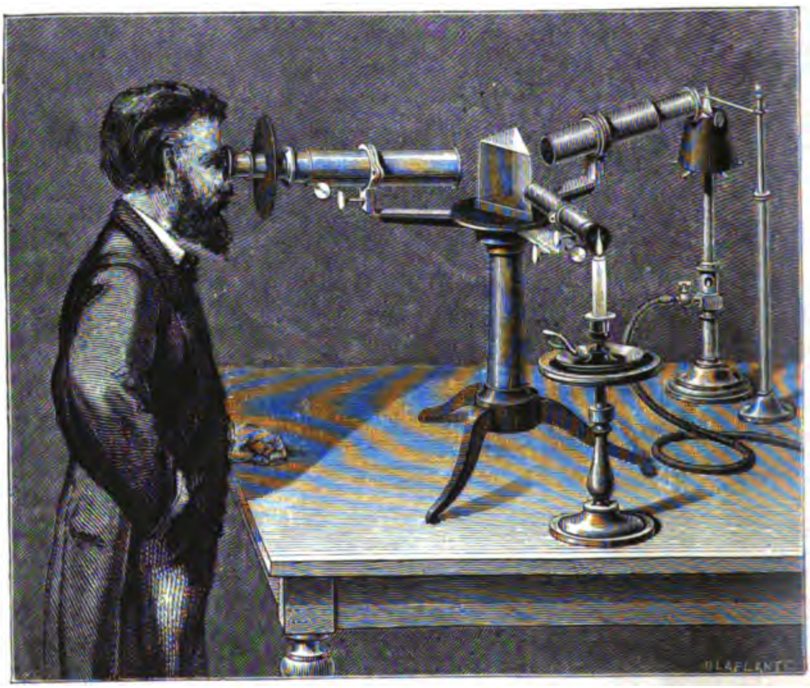
Spectroscope with Line of Light for Measuring the Distances between the Lines.

being silvered; and upon the front edge a narrow line is cut through the silvering. If a ray of light falls perpendicularly upon the upper unsilvered surface in the direction of the arrow 2, it passes unrefracted through the glass, and, being reflected from its slanting surface, emerges through the narrow line in the direction 3.

In Fig. 45*b* is shown the position of the small glass plate P in the spectroscope R R, immediately behind the eyepiece O O, and the method of illumination by the mirror S. The glass plate is fixed into the short brass tube *u*,

and projects into the spectroscope only so far as to allow the point of the line of light to be visible over the spectrum. The ring *t* carrying the axis of the small mirror turns upon the tube *u*, while the mirror revolves upon an axis of its own. By this double motion it is possible to give any degree of intensity to the line of light, which,

Fig. 46



The Complete Spectroscope.

as will be seen, takes the direction 1, 2, 3, while the spectrum reaches the eye in the direction 4.

The line of light being stationary, it is requisite that the portion of the spectrum to be examined be made to traverse this line, either by the revolution of the prism or the displacement of the slit.

28. The Complete Spectroscope.

The reader is now in a position to understand the use of the various parts of a complete spectrum apparatus, such as that constructed by Kirchhoff and Bunsen, and shown in Fig. 46. The eye of the observer is placed in the axis of the telescope, directed to that surface of the prism from which the dispersed light emerges to form the spectrum. The opposite surface of the prism receives as parallel rays

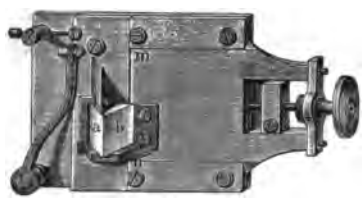
Fig. 47.

Improved Complete Spectroscope.

the light emitted from the source which comes through the slit and collimating lens. At the side of the observer is the tube, carrying the illuminated scale, or the micrometer screw for determining the position of any line. A spectroscope on the same principle, but furnished with modern improvements, is shown in Fig. 47. The three chief parts—the collimator tube C, with its adjustable slit S; the observing telescope F; and the micrometer tube A, with its movable scale—are each inserted into a central brass box, containing the prism. This is placed vertically upon an adjustable platform, and

when greater dispersive power is needed, it can readily be removed, and replaced by one of bisulphide of carbon. The cover D serves to exclude all side light. The collimator tube C is permanently fastened to the box, but the two other tubes, F and A, are capable of a gradual movement in a horizontal plane by means of the screws *f* and *a*. By reversing the screws, the pressure of spiral springs brings the tubes backwards by an equally gradual movement. The motion of the telescope is necessary in order to bring the cross-wire upon any portion of the spectrum, while the motion of the micrometer tube A is to enable the observer to place any division of the scale in

FIG. 48.



The Comparison Prism, or Reflecting Prism.

accurate coincidence with some fiducial line of the spectrum from which to start the measurements. For the illumination of the scale, a candle or gas-burner is placed at A, or, when reflected light is needed, a plane mirror, movable in all directions, may be adapted. An adjustable platform *b c d* is suspended from the collimator tube, on which cells containing liquids may be placed in front of the slit for the study of absorption phenomena.

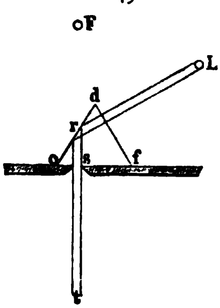
29. COMPARISON PRISM, OR REFLECTING PRISM.

Although accurate maps, drawn to scale, of the spectra of various substances have been constructed (Plate XIV.),

which form a valuable standard of comparison, yet their practical use is attended with many difficulties. A simple and more trustworthy method is that adopted by Kirchhoff (Fig. 48), by which the upper half of the slit alone is employed for forming the spectrum to be examined, the lower half being covered by a small equilateral prism *a b*, by which a second comparison spectrum can be formed.

A reference to Fig. 49 will explain this arrangement. F is the source of light whence the rays pass through the upper half of the slit and form a spectrum in the lower half of the field of view. At one side, and level with the prism, the flame L is placed, in which the substance is volatilized, the spectrum of which is needed for comparison. The rays from L, falling at right angles on the surface *d f*, will be totally reflected as by a mirror from the surface *d c* at the point *r*, and will emerge from the prism in the direction *r s*, pass at *s* through the lower half of the slit, and fall in the direction *s t*, on the lower half of the principal prism, in the same manner as the rays from F fell on the upper half.* In this way the spectra *o* and *u* of the two flames F and L are seen in juxtaposition in the same field of view as shown in Fig. 50, where, for greater clearness, they are represented as thrown upon a screen. In reality, as the spectra *o* and *u*

FIG. 49.



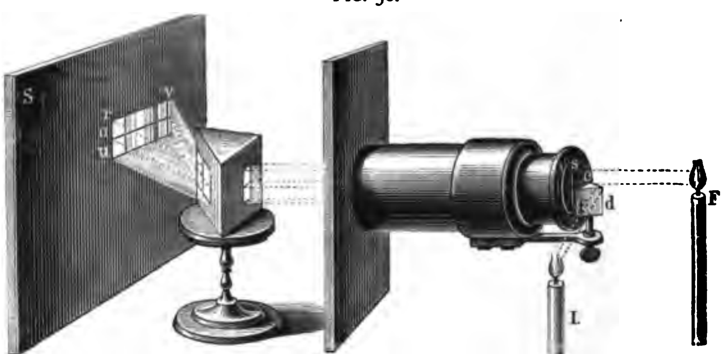
The Comparison Prism.

* [The light passing through each half of the slit is not restricted to the corresponding part of the prism, but since it consists of diverging rays, spreads itself over the collimating lens and then passes through the prism as a beam of parallel rays of the same diameter as the lens.]

are viewed through a telescope, their positions are reversed. If the same substance is volatilized in the two flames F and L, the corresponding lines of one spectrum should fall in exact prolongation of those of the other, as the two pencils of rays have the same constitution and should produce precisely similar spectra, the width of slit, the prism, and the position of the telescope being the same.

In doubtful cases therefore, if a small quantity of the suspected substance be volatilized in the second flame, its

FIG. 50.



The Double Spectrum.

presence will at once be proved by the complete coincidence of the lines in the spectrum. The extreme delicacy of this test renders it one of the most important processes in spectrum analysis.

For the ready comparison of various spectra, it is convenient to have at hand the means of producing the spectra of known elements. Such are given by saturating the wicks of small wax or tallow candles with the various metallic compounds of chlorine.

When great accuracy is required in the comparison of two spectra, the reflecting prism must only be used after the

absolute truth of its surfaces has been satisfactorily tested, and even then various precautions are necessary, which form obstacles to its employment. On this account Dr. Huggins, in his researches on the spectra of nebulæ and fixed stars, associated with the reflecting prism a silvered mirror by which the light of the terrestrial substance was also reflected into the slit. He thus produced *two* spectra, one above and the other beneath the stellar spectrum, which they both slightly overlapped, and by this means greatly facilitated the comparison of the lines. It is, however, always safest to throw the light from the terrestrial substance direct into one half of the slit, without reflection, an arrangement adopted by Dr. Huggins in his extremely delicate observations on the spectra of nebulæ.

30. The Compound Spectroscope. Train of Prisms.

A spectroscope is termed compound when it consists of several prisms, or trains of prisms. The position of the prisms is a matter of importance, as the purity of a spectrum depends upon each prism being placed in the angle of minimum deviation for the portion of the spectrum under observation. To secure this the prisms must either be individually adjustable, or must be so connected that when one prism is placed in the position of minimum deviation for a given coloured ray, the others will also occupy a similar position.*

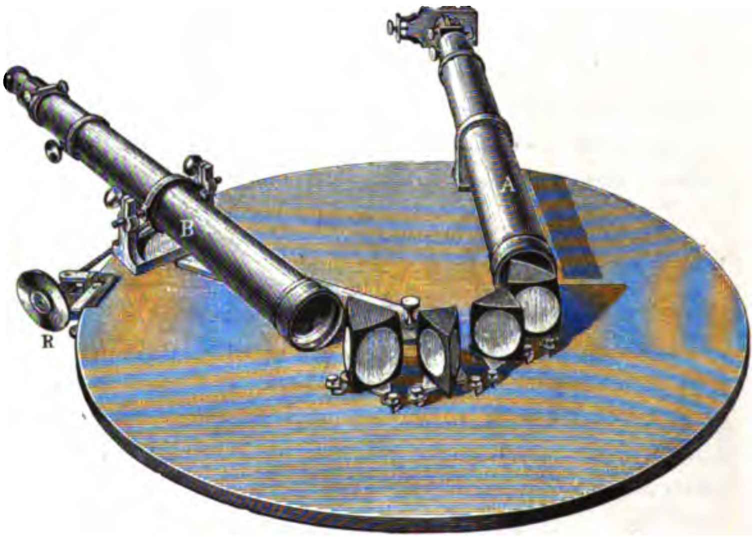
Kirchhoff employed in his investigations on the solar spectrum an excellent apparatus constructed by Steinheil, of Munich, in which, instead of only one prism of flint glass,

* [The necessity of placing prisms at their angle of minimum deviation when a collimator is used is overrated. The effect of a deviation from this position is to alter the breadth of the lines, and at the same time to proportionally alter the length of that part of the spectrum.]

on

four such prisms were employed, and a telescope with a magnifying power of 40. Three of the prisms (Fig. 51) had refracting angles of 45°, and the fourth one of 60°. These four prisms were cemented on to small brass tripods and placed on a flat iron table. They could thus be easily adjusted to the position of minimum deviation for every ray under investigation. The tube A, which was

FIG. 51.



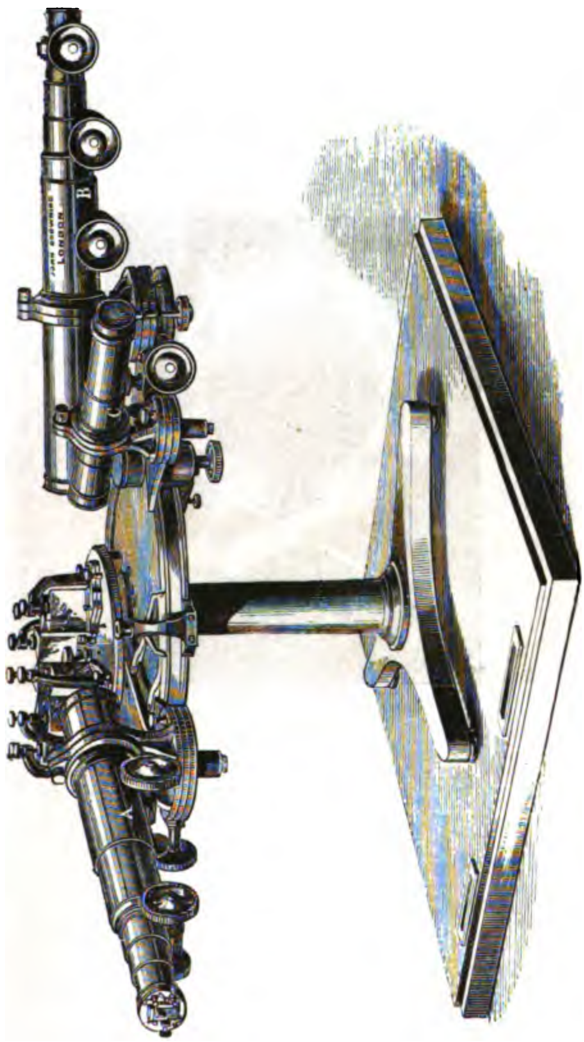
Kirchhoff's Spectroscope.

directed towards the sun, carried the slit with the comparison prism (Fig. 48); the telescope B, which received from the last prism the widely diverging rays of the solar spectrum, could be moved by means of a micrometer screw R, on a divided circle, so as to determine the distance between any of the dark lines in angular measure.

This amount of dispersion has been, however, surpassed; Thalén employed six flint-glass prisms, each having an angle of 60°; Gassiot went as far as eight, Merz even to

eleven prisms of glass, while Cooke made use of as many as nine prisms of bisulphide of carbon, and Donati even

Fig. 52



Large Spectroscope of the Kew Observatory.

of 25 prisms of glass. Fig. 52 shows one of the largest spectroscopes yet made, used by Gassiot at the Kew

Observatory for the investigation and mapping of the solar spectrum. The tube A carries the collimating lens, the slit, and the comparison prism; the nine prisms rest, as in Kirchhoff's instrument, on small plates provided with levelling screws upon an iron table; B is a telescope of high magnifying power; C, a tube fitted with a scale. The thin slice of light entering the first prism from the slit and colli-

FIG. 53.

Path of the Ray through the Nine Prisms.

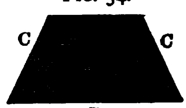
mator tube A passes through the range of nine prisms, as shown in Fig. 53, and finally emerges from the last prism and enters the telescope B in the form of a widely dispersed beam. The prisms in this instrument are of the heaviest lead glass, having a specific gravity of 4·75, so that one such prism of 60° is equal to the four in Kirchhoff's spectroscope (Fig. 51).* The spectrum must evidently in such

* [Very dense glass has the disadvantage of not being colourless. In lead glass the absorption of light due to this cause is almost wholly confined to the infra red and to the part of the spectrum more refrangible than F.]

an instrument be exceedingly extended, and but a very limited portion of it can be visible in the field of view of the telescope. In all such instruments, therefore, the telescope must either revolve round the plate on which the prisms rest, and the amount of motion be registered by a micrometer upon the divided edge of the circle, or the train of prisms must themselves revolve, so that any portion of the spectrum may be brought into the field of view.

The principle of compound prisms has been advantageously introduced into the spectroscope, an example of which is given in Fig. 54, where a dense flint-glass prism is inserted between two small crown-glass prisms. If the central prism F of heavy flint glass has a refracting angle of from 90° to 100°, according to the nature of the glass, the lateral crown-glass prisms C C should have an angle about one-fourth as great, and should be cemented on to the central prism, their bases being at the refracting edge.

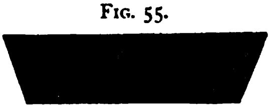
FIG. 54.



Composite Prism.

The dispersion thus obtained is equal to that of two single prisms of dense glass with an angle of 60°, while the amount of deviation scarcely exceeds that of a single prism. The loss of light is also less, for whereas in two single prisms there are four reflecting surfaces, there are but two in the compound prism, for the reflection from the cemented surfaces may be disregarded. The hard crown glass acts as a valuable shield to the softer but heavier glass.

FIG. 55.



Rutherfurd's Compound Prism.

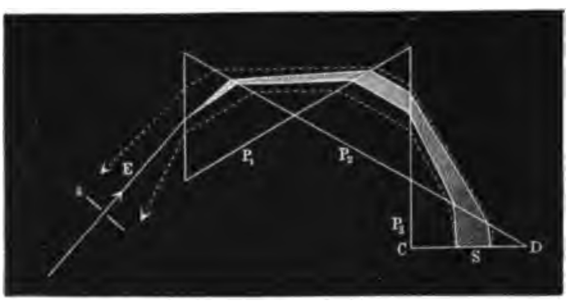
The most advantageous arrangement of such prisms is doubtless that devised by Rutherfurd (Fig. 55), which consists of five prisms cemented together; the two which are darkly shaded in the drawing are of dense flint glass, with a refracting angle of 90°, while

the others in lighter shade are of crown glass. The dispersive power of such a prism is nearly equal to that of three single flint-glass prisms of 60°, and the loss of light is sensibly less than with three ordinary prisms.

31. Twofold Passage of the Rays through the Prism. Return of the Rays.

An important improvement has been introduced into the spectroscope by Littrow, of Vienna, by which the amount of dispersion can be doubled without an increase in the number

Fig. 56.



Littrow's Combination of Prisms.

of the prisms. After leaving the collimator the light passes through a train of four prisms, when, instead of emerging, it is by means of the reflecting surface of the fourth and last prism made to return and pass again through the train of prisms, whereby it becomes still further dispersed. The spectrum is received upon a prism of total reflection placed near the slit, by which it is directed into the field of view of the eye-piece. Fig. 56 exhibits this double course of rays through two prisms. S is the slit, P_1 and P_2 are the two prisms, P_3 a half-prism of similar size, the surface of which C D is silvered so as to act as a mirror. E is the incident ray the path of which is marked through the prisms

up to the reflecting surface C D, whence the return path is indicated by the dotted lines.

The inconvenience arising from the rays crossing one another in passing twice over the same course has been successfully combated by both Young and Lockyer, each working independently of the other. By the introduction of a right-angle isosceles prism, the rays in their first passage are thrown by reflection through the lower half of the prisms, and on their return they are, by a second reflection, made to pass through the upper portion of the prisms.

This device, as applied to a single prism P_1, is shown in Fig. 57. The incident ray *e* emerging from the slit *s* and collimator tube C passes first through the prism P_1 in its upper half, and then enters the supplementary double reflecting prism R, from the upper surface *a* of which the rays, already somewhat dispersed, are reflected on the lower surface *b*, and thence again through the prism P_1 in its lower half, as indicated by the arrow heads. The refraction of the light by the prism is disregarded in the diagram. The amount of dispersion having been by this means doubled, the spectrum on finally emerging from prism P_1 is received by the small reflecting prism *r*, by which it is conducted into the telescope F.

32. The Automatic Spectroscope.

An ingenious contrivance for maintaining a constant position of minimum deviation is to connect the prisms together by one corner of the base, by which means they are made to approach or recede automatically from a common centre at a uniform rate. Thus when the prisms are once fixed in the position of minimum deviation for any one colour, the same position for any other colour is readily secured.

Ordinary spectroscopes consisting of one or more prisms are usually adjusted by finding the minimum of deviation for the *brightest* rays,—those, for instance, situated between the

FIG. 57.

Improved Combination of Prisms with Reflection.

yellow and the green,—for each prism which is then permanently clamped to its supporting plate. There are, however, two objections to this arrangement. In the first place, only those rays for which the prisms are specially adjusted are

seen under the most favourable circumstances, because they only pass through each prism in a line parallel to the base. In the second place, since the last prism is immovable, while the telescope travels in an arc from one end of the spectrum to the other, the object-glass of the telescope receives the full light only when it is directed to the central part of the spectrum; and, on the contrary, only a part of the light falls on the object-glass when the telescope is directed to either end of the spectrum.

Now it is easy to see that in observing the ends of the spectrum it is most important that the object-glass should receive the whole of the light, since it is just these terminal colours that have the least brilliancy. This can only be accomplished by adjusting the prisms for the minimum of deviation for those rays which are under examination.

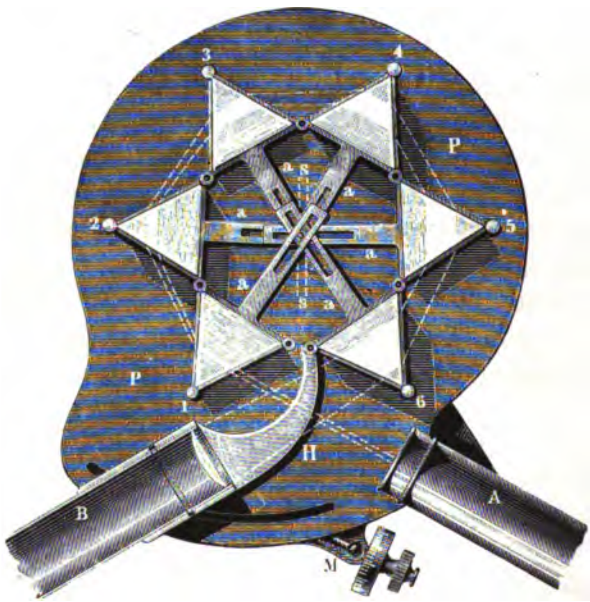
Bunsen and Kirchhoff, therefore, in their investigations of the solar spectrum, attached the prisms of their compound spectroscope (Fig. 51) to the ground-plate by means of movable supports, and altered the position of the prisms for every colour of the spectrum; it is needless to remark that such an arrangement involved much trouble and inconvenience. Littrow's contrivance obviated much of this inconvenience, but it was left to Browning to devise and construct an apparatus which for simplicity and accuracy leaves nothing to be desired; to this instrument he has given the name of the *automatic* spectroscope.

As the name implies, the prisms are so connected with each other and with the telescope that, by directing the instrument on any particular colour, the prisms are simultaneously and automatically adjusted for the minimum of deviation for that colour.

Fig. 58 shows the arrangement of the various parts of the automatic spectroscope. Of the prisms, numbered from 1 to 6, only the first is fastened to the ground-plate P P; the

others are connected to each other by hinges at the corners of the triangular metal holders forming the base. A metal rod *a*, provided with a slit, is attached to the middle of this base, by means of which each prism can move round a central pin common to the whole set. The prisms are arranged in a circle round this pin, which again is fastened to a swallow-tailed movable bar *s s* about two inches in length, situated

FIG. 58.



Automatic Spectroscope.

under the plate P P. If, therefore, the central pin is moved, the whole system of prisms moves with it, and the amount of motion communicated to each prism varies in proportion to its distance from the first prism, which is stationary; if, for instance, the second prism moves 1°, the third is moved 2°, the fourth 3°, the fifth 4°, and the sixth 5°. The tube of the

telescope B is fastened to a lever H, which is connected by a hinge with the last prism, No. 6. At the other end of this lever, or on the carrier of the telescope B, works the micrometer screw M, by turning which the tube B can be directed upon any part of the spectrum issuing from prism 6.* This lever is so adjusted, that to whatever angle the telescope is turned, the amount of movement for the last prism is twice as great. The rays emerging from the middle of the last prism fall perpendicularly upon the centre of the object-glass of the telescope; the rays issuing from the collimator A, and falling upon the first stationary prism 1, pass through each prism in a line parallel to its base, and arrive finally, on their emergence from the last prism, 6, in the direction of the optical axis of the telescope, whether it be directed upon the central or the terminal colours of the spectrum ; the object-glass is consequently always filled with light. As the tube B is turned towards any colour of the spectrum, the lever H sets at the same time all the prisms in motion, in such a manner that each adjusts itself to the minimum angle of deviation.

33. SCHRÖDER'S SPECTROSCOPE.

Where space is limited, the spectroscope constructed by Schröder for the Hamburg observatory is well adapted.

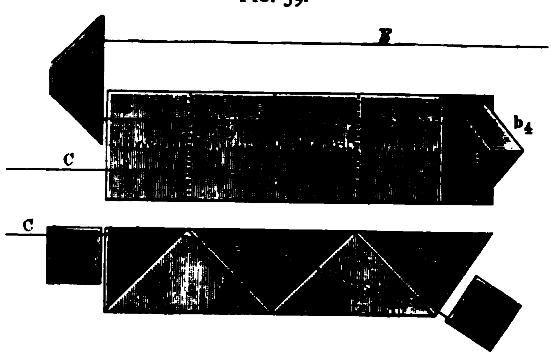
The composite prism consists, as shown in Fig. 59, of two rectangular prisms, a_1, a_2, of dense glass in combination with three crown-glass prisms, b_1, b_2, and b_3. The angles are so calculated that the ray c falls perpendicularly upon the lower part of the prism b_1. The central ray of the spectrum emerges from the prism b_3 in a direction perpendicular

* [It is dangerous to trust to the angular movement of the telescope as an accurate measure of the distance between two lines, on account of mechanical imperfections which must exist.]

to its surface, and enters the reflecting prism b_4, whence it is sent back through the upper half of the compound prism. It emerges from b_1 also in a perpendicular direction, and enters the small reflecting prism b_5, whence by double reflection it is conveyed into the telescope F, which is in a fixed position.

By the axial motion of the reflecting prism b_4, the whole of the spectrum may be brought successively into the field of view; the addition of a micrometrical arrangement can easily be effected.

FIG. 59.



Schröder's Compound Prism.

An instrument of this construction offers the advantages of simplicity and handiness, and the loss of light either through absorption or reflection is inconsiderable.

34. The Registration of the Lines of the Spectrum.

In certain kinds of observation, such as those of a total solar eclipse or the investigation of very evanescent substances, the phenomena are too fleeting to allow the registration of the position and intensity of all the lines observed in the spectrum, either by means of the scale or by the micrometer screw. In such cases it is of great

assistance to have some arrangement by which the relative positions of the lines, as seen in the spectroscope, may be rapidly and exactly sketched on paper or scratched upon metal or glass.

A very simple contrivance for this purpose has been devised by Dr. Huggins, consisting of a very delicate pointer fixed in the eye-piece and regulated by a coarse threaded screw, so as to travel rapidly over the whole length of the spectrum. By a special contrivance the observer is enabled at once to register the position of any line in the spectrum upon a band of paper. The pointer lies in the focus of the observing telescope, which is stationary; but the eye-piece possesses a backwards and forwards motion by which any portion of the spectrum can be quickly brought into the centre of the field and placed above the pointer. An arm is connected with the pointer by a lever which carries two fine needles that move about two inches when the pointer is carried from one end of the spectrum to the other. A strip of paper, stretched over a frame, which can be placed successively in five different positions along the spectrum, is placed beneath these needles. When the arm is pressed down, the needles make a prick in the paper; and by moving the frame the position of the paper under the needles may be changed five times, and each portion used for the registration of a different spectrum.

To record the position of a line, one hand brings the pointer, by means of a screw, upon the spectrum line that is to be registered, and the other presses the needles, making a prick in the paper. The more intense lines are indicated by both needles making pricks, one under the other. After repeated trials, it has been proved that by this contrivance from ten to twelve Fraunhofer lines may be registered in about fifteen seconds, and that if the same line has been recorded five times in succession upon the

same sheet of paper, no perceptible variation is discoverable in its position in the five spectra. This contrivance is therefore specially advantageous when comparing the relative positions of the individual lines in the spectra of various substances.

Professor Winlock, when observing the total eclipse of the sun of December 22nd, 1870, made use of a method of registration in which the position of the lines of the spectrum, as seen in the telescope, was marked upon a plate of silvered copper.

35. The Wave-lengths : Abnormal Dispersion.

It has already been pointed out—§ 15—that while the velocity of the waves of light in the free ether of space is the same for all colours, yet that in passing through a refracting medium the velocity for the different coloured rays varies according to the difference in their wave-length, and that this was due to the action of the material molecules upon the ether molecules. It was found that when passing through a refracting medium the rays of shortest wave-length were more retarded, as a rule, than were those of greater wave-length. The rays therefore of shortest wave-length—in other words, the waves of most rapid vibration — are characterized by their greater deviation, and consequently their greater retardation in passing through a refracting medium.

To ascertain the number of vibrations of a ray of light,—that is to say, the number of the oscillations of a molecule of ether in *one* second,—the speed of propagation must be divided by the wave-length; therefore if λ be the wave-length, n the number of vibrations, and c the velocity, then the equation is always $n = c \div \lambda$.

When a ray of homogeneous light passes from one medium

to another, ***the number of vibrations remains the same,*** but a change takes place in the wave-length and in the speed of propagation. The characteristic of a ray which produces the sensation of colour is therefore neither the wave-length nor the speed of propagation, but the ***number of the vibrations*** beating upon the retina of the eye, and this is not affected by the passage of a ray from one medium to another.

If the passage of a ray of light through the air be represented by the foregoing quantities c, λ, n, and the speed of propagation and wave-length of the ***same*** ray when passing through another refracting substance be represented by c_1 and λ_1, then for this latter medium the equation will also be $n = \frac{c_1}{\lambda_1}$ and therefore $\lambda_1 = \lambda\frac{c_1}{c}$. The proportion $\frac{c}{c_1}$ of velocity in the two media is, however, nothing more than the coefficient of refraction of air to the denser medium. If this be represented by k, then $\lambda_1 = \frac{\lambda}{k}$, that is to say, ***the wave-length of a ray of light in any medium is obtained by dividing the wave-length in air by the coefficient of refraction of the medium.*** The coefficient of refraction for the passage of light from ***a vacuum*** into ***air*** may be regarded as the same for all colours, and may be taken as 1·000294. When therefore the wave-length of a ray of light in air has been found, the wave-length in vacuo is obtained by multiplying the result by 1·000294. The ***number of vibrations*** per second* is then found by dividing the speed of propagation by the wave-length, and the duration of a vibration by dividing a second by the number of these vibrations.

In most colourless refractive media, such as glass, bisulphide of carbon, water, the rays of shortest wave-length, that is, of most rapid vibration, are more deflected than the

* [Usually called the oscillation frequency.]

rays of greater wave-length or of less rapid vibration. For this reason prisms formed out of such substances yield a spectrum in which the individual colours follow the ordinary (normal) order of succession; the red rays, or those of greatest wave-length, are the least deflected, and the violet rays, or those of shortest wave-length, are more so.

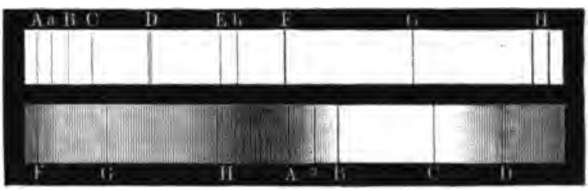
This is, however, not the case in a great number of coloured transparent media in which the material molecules exert a completely opposite influence upon the propagation of the ether waves. If, for instance, a hollow prism of glass is filled with a concentrated alcoholic solution of fuchsin or naphthalin red (*Magdala*), etc., and the light from a brightly illuminated slit is viewed through it close to its refracting edge, a spectrum will be seen in which the violet and the blue rays are less deflected from the angle of incidence of the white light than are the red or yellow rays. Such a spectrum begins with violet, after which comes blue, then a colourless space where green is usually found; beyond this space lie yellow and orange, and the spectrum ends with red in the place of greatest deviation. The succession of the colours is the reverse of that of a normal spectrum: the rays of most rapid vibration (violet and blue) are the least deflected, and the rays of least rapid vibration (yellow and red) are the most. We may therefore conclude that in these coloured substances the influence of their material molecules in retarding the vibration of the ether particles is less powerful upon the rays of shortest wave-length, the violet and blue rays, than upon the rays of greatest wave-length, the red and yellow rays. This phenomenon, first observed by Christiansen and afterwards more closely investigated by Kundt, is termed *Abnormal dispersion*. In order to observe it, special contrivances are requisite, so as to secure the utmost amount of concentration in the coloured solution, and yet to allow sufficient light to pass through the prism;

it is also necessary to eliminate as much as possible the disturbing influence of the substance from which the solution is prepared.

According to Christiansen a concentrated alcoholic solution of fuchsin gives the following coefficients of refraction :

Fraunhofer Line.	Coefficient of Refraction.
B	1·450
C	1·502
D	1·561
F	1·312
G	1·285
H	1·312

FIG. 60.



Abnormal Spectrum of Concentrated Infusion of Fuchsin (Solar Spectrum above).

The coefficients of refraction augment therefore in the usual proportion from B to D, and even a little beyond D, and then sink suddenly in an abnormal manner to G, after which they begin again to increase. Thus the yellow has the most and the violet the least deviation, and consequently the Fraunhofer lines no longer succeed each other in the same order as in an ordinary solar spectrum : they rather present the appearance as if the two halves of a normal spectrum had been transposed.

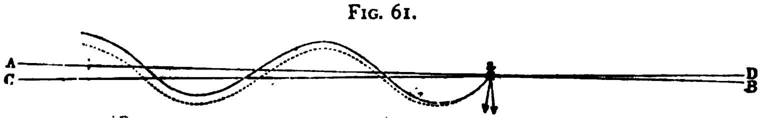
Fig. 60 represents the abnormal spectrum as produced by a concentrated solution of fuchsin, above which is given the normal solar spectrum.

36. Interference of Light and Measurement of the Wave-Lengths.

When several rays of light, or systems of ether waves, encounter one another in their passage through a medium, certain phenomena are produced, which owe their origin to the fact, that while in some directions the rays of one system fall in with and strengthen those of another system, in other directions they weaken or even destroy them.

In Fig. 61 two such systems of waves, corresponding to the rays of light A B and C D, are represented, which are travelling in very close proximity, and meet at the point *a*. The two wave-lines represent the combined altitudes for

Fig. 61.

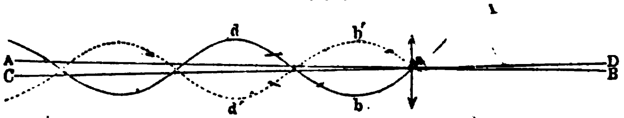


Illustrative Diagram of Two Waves increasing each other in Intensity.

some one moment of the vibrating ether molecules as they are propagated in the direction of the rays A B and C D. If both rays have travelled equal distances from the source of light to *a*, then the molecule *a*, which is preparing to move downwards from the point of rest between A B and C D, will swing downwards with a force twice as great as if the impulse came only from the individual ray A B or C D. There is therefore at the point *a* an increase in the force of vibration, or, in other words, an increase in the intensity of light. This is always the case when the starting-points of two systems of waves eventually cross each other, or are slightly inclining to one another, if they are separated by the distance of an exact wave-length, or by 1, 2, 3 . . . whole wave-lengths, or an *even* number of *half* wave-lengths.

Fig. 62, on the other hand, represents the two waves of equal wave-length, which have not started from the same point, but which, when they reach the point *a*, where they cross, are separated by a *half* wave, or by some *uneven* multiple of a half wave. The ether molecule *a*, lying in the point of rest between the two rays, will receive from the one wave-system an impulse upwards, and at the same instant an impulse downwards from the other wave-system. Should each wave-system be of equal wave-length and equal intensity, the forces directed upon *a* will neutralize or destroy each other, and the molecule will remain at rest. The same is true for the other ether molecules *b*, *d*,

FIG. 62.



Illustrative Diagram of Two Waves destroying one another.

etc., whenever the rays A B and C D meet, or approximately meet; the second half of the first wave coincides with the first half of the second wave; the hollows of the first wave coincide with the crests of the second wave. The impulse given to the ether molecules by the one wave is exactly counterbalanced by the impulse given by the other, and the two waves mutually annul and destroy one another.

When the distance separating two waves of light lies between the above-mentioned limits, or the waves are not exactly of equal length, then there is neither in the one case a doubling of the force of vibration, nor in the other case a complete destruction of it. The effect of two such systems of waves meeting lies between these extremes, that is to say, there is either a partial increase or a partial decrease in the intensity of the light.

The correctness of this representation—the phenomenon known as the *Interference* of light—may be proved by a number of different experiments: they all confirm the pro-

Fig. 63.

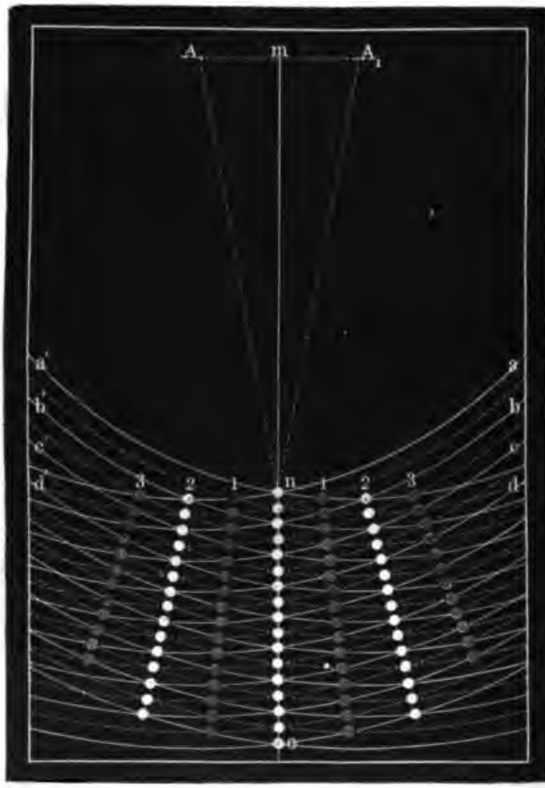


Diagram illustrating the Interference of Light.

position that light added to light *will, under certain conditions, produce complete darkness.*

We cannot further enter here into the details of these experiments, and must confine ourselves to the examination of a single instance of the interference of rays of light. Let A and A_1 in Fig. 63 be two points very near to each other,

which emit a continuous stream of light under circumstances which enable the ether molecules A and A_1 to preserve the same phase of vibration. Between the points A and A_1 let the central point *m* be found, upon which erect the perpendicular *m n*, and from each point A and A_1, with radii reaching thence to the perpendicular, describe a series of concentric arcs, *a, b, c, d* . . . and *a', b', c', d'* . . . which shall be at equal distances from one another. It is manifest that all points in the arcs *a* and *a'* are relatively equi-distant from the sources of light A and A_1, and that this must be true also of the arcs *b* and *b'*, *c* and *c'*, etc. If, therefore, as it has been assumed, the ether molecules at A and A_1 are vibrating under precisely similar conditions, it follows that all the ether molecules in the arcs *a* and *a'* will vibrate also under similar conditions, and the same is true not only of every molecule in the succeeding arcs *b* and *b'*, but of all the molecules in every such pair of arcs which are equi-distant from A and A_1.

If from the same two points A and A_1 other concentric arcs are described exactly in the middle between the arcs already drawn (marked in the figure by dotted lines), then, as before, all molecules found in any two of these arcs, which are equi-distant from A and A_1, are also in the same phase of vibration, although these conditions are not the same as those of the molecules in the arcs *a, b, c, d* . . . If the distance between any two of the first set of arcs *a, b, c, d* . . . is a whole wave-length, then the distance between these and the second set of arcs—dotted arcs—is a half wave-length. The ether particles in the arcs *a, b, c, d* . . . are therefore in quite the opposite phase of vibration to those in the dotted arcs. Now, as the two wave-systems cross each other, there will be at the point of crossing an increase in the intensity of the light where the ether molecules are in the same phase of vibration—

that is to say, at the point where the arcs *a, b, c, d* . . . intersect the arcs *a′, b′, c′, d′* . . . as well as where the dotted arcs intersect one another. These places are marked in the figure with a small white circle. But in those places where the dotted arcs cross the arcs *a, b* or *a′, b′*, the difference in the wave-lengths from A or A_1, as the light progresses in its course, amounts to $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$ . . .; therefore at such points of intersection the ether particles of the waves encountering one another are in precisely opposite phases, and their motion is consequently annulled. At these places, marked in the figure with a small dark circle, a complete interference of light takes place; in them the ether molecules are at rest, and therefore emit no light; they are places of complete darkness.

When it is remembered that, as the wave of motion proceeds from *a* to *b*, from *b* to *c*, etc., the ether molecules lying in the path pass progressively through all the phases of a vibration, it is easy to see that the points of greatest intensity, as well as the points of darkness, should form themselves into continuous lines. An increase of light therefore will be observed, where the arcs intersect, along the whole central line *n o*, and along the lines marked 2; while along the lines marked 1 and 3 complete darkness occurs. If it is further remembered that the wave motion, proceeding from A and A_1, is propagated not merely in a plane, but in a spherical form, in every possible direction, so that the arcs *a, b, c* . . ., *a′, b′, c′* . . ., as also the dotted arcs, are to be viewed as portions of a hollow sphere, then it is evident that if the complete wave-system be received upon a screen or upon the retina of the eye, the phenomena of interference will present the form of alternate bright and dark bands, the central one, *n o*, being a bright one.

It has been assumed that the ether waves proceeding from A and A_1 are uniformly of the same wave-length *a b*.

The figure, however, clearly demonstrates that the smaller the wave-length, the nearer will the bright and dark bands approach each other. Fresnel investigated this phenomenon in the following manner. By means of two mirrors, inclined to each other at a very obtuse angle, he produced, from one luminous point, two closely approximate images (A and A_1). Now as, in accordance with the laws of optics, the rays reflected from the mirrors, in their passage from the luminous point in front of the mirrors to the arcs a, b, c . . . or a', b', c' . . ., will pass over the same path as if they started from the images A, A_1, the condition is fulfilled, that the ether particles at A and A_1 are in one and the same phase of vibration — namely, in that of the luminous point. Upon substituting a bright line for the luminous point, and receiving upon a white screen or examining with a lens the two wave-systems reflected from the mirrors, Fresnel found a succession of alternately bright and dark bands, symmetrically arranged on either side of the central and brightest line $n\ o$. When he made use of red light, the red bands became broader and more separated; with yellow light they were narrower and nearer together, and still more so when violet light was used. From this it follows that the wave-length of a red ray is greater than that of a yellow ray, and the wave-length of a yellow greater than that of a violet ray. A simple application of geometry demonstrates that the width of band is in exact proportion to the wave-length, and that the wave-length may be ascertained when the width of the bands, the amount of their separation, the distance of the two images A and A_1 behind the mirrors, and their distance from the screen are given.

As the dark bands indicate the extinction of light at those places, and the point of extinction is not the same for all colours, it is not possible, when using white light, to obtain

the bright bands perfectly white, nor yet the dark bands completely black. There must always be some admixture of colour, but on account of the difference of luminosity of the individual colours, there still will be an alternation of dark and bright bands.

37. Diffraction of Light.

As early as 1665 Grimaldi observed that the image of the sun, formed by a small round aperture in the shutter of a darkened room when received upon a screen, was somewhat larger than it ought to be, taking the size of the aperture into account, supposing the rays of light travelled in a straight line. He also noticed that the image was surrounded by faintly-coloured rings. When the small hole was replaced by a narrow slit, and a small opaque body placed in the path of the solar rays, there appeared on the screen a shadow, that was not merely broader than it ought to have been, but was marked on either side by several coloured bands. When the light was admitted through two small round holes close to one another, and the screen so placed that the two small images of the sun overlapped, it was noticed that in the locality which received light from the overlapping images, and which might therefore be expected to be doubly luminous, dark bands were visible. On closing either of the apertures these bands immediately disappeared. Grimaldi was thus led unhesitatingly to announce the proposition, though its full meaning was not yet clear to him, that, under certain conditions, light added to light produces darkness. He undoubtedly recognised the immediate cause of this phenomenon, since he assumed that the rays of light, in passing by the edges of the opaque object, had suffered a *deflection* from their straight course, and had afterwards proceeded as a diverg-

ing brush of light. To this phenomenon he therefore gave the name *diffraction* of light.

In the study of diffraction a number of complicated phenomena present themselves, to all of which an explanation is afforded by the undulatory theory of light. The importance of some of these phenomena will appear from the following simple experiment, which affords the means of ascertaining with great accuracy the wave-lengths of different colours.

FIG. 64.

Exhibition of Diffraction Bands.

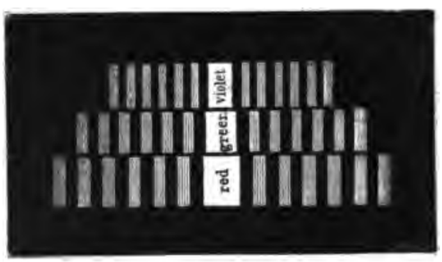
Through the narrow vertical slit A (Fig. 64) in the window-shutter F F, let a pencil of solar rays A B enter a dark room, and at B allow it to pass through a second slit, parallel to the first, after which let it be received upon a white screen placed at some little distance from the latter. Not only is the spot *a* brilliantly illuminated where the pencil of light A B would fall on the screen if the rays had travelled only in a straight course, but beyond the bright band *a*, lying on each side of it, is a succession of coloured and dark bands a_1, a_2, a_3, etc. The bands diminish in brightness the further they are removed from the centre *a*, until they become so faint as to be indistinguishable from the background. In passing through the narrow slit B, the rays are diffracted or bent, so as to spread out on each side.

These phenomena closely resemble those exhibited in

Fresnel's experiment with the mirrors; and in both cases it is equally necessary to employ homogeneous light—light of one colour—to obtain distinctly separated dark and coloured bands, as shown in Fig. 65.

With yellow light the dark and bright bands are broader than with violet light, and with red light they are broader still in the proportion represented in the figure. If we imagine these coloured images to be superposed, it will be at once perceived that by the employment of white light, which is composed of all shades of colour, very confused images

FIG. 65.



Fraunhofer's Spectra of the First Order.

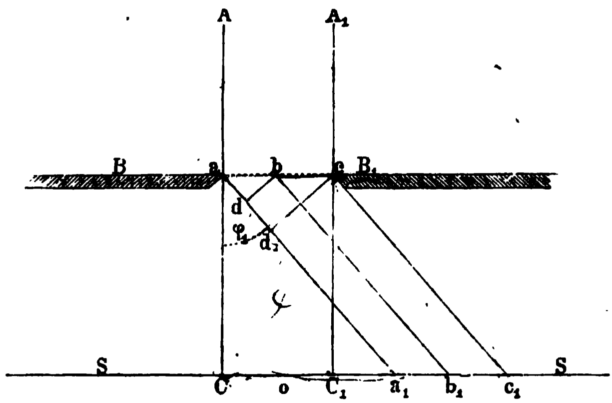
will result, for the bright bands will no longer be of uniform tint; nor the dark bands wholly black. If the slit B is gradually widened, the bands become narrower, until with a moderately wide slit they become so fine as to be no longer visible.

Fraunhofer, by whom these experiments were in a sense carried to completion, inasmuch as he succeeded in registering in detail the phenomena of the diffraction of light, applied the term *spectra of the first order*, of the *second* order, and of the *third* order to those images marked a_1, a_2, a_3 respectively . . . (Fig. 64) on either side of the band a.

We will now endeavour to explain the formation of these

spectra and the dark bands. Let *a c*, in Fig. 66, represent the opening of the slit B B_1 and A A_1, a pencil of homogeneous light—red, for instance—in which all the ether particles lying along the slit are in the same phase of vibration. According to the axiom laid down by Huyghens, every vibrating ether particle becomes the centre of a new spherical wave-system, expanding in all directions. Every ether particle, therefore, lying between *a* and *c*, forms the centre of a spherical wave, extending equally towards A A_1 and the

FIG. 66.



Explanation of Diffraction Bands.

screen S S. If, as we have assumed, all the atoms between *a* and *c* are in the same phase, then in the space between *a* C and *c* C_1 all the atoms lying on any line parallel to *a c* will likewise be in the same phase. None of these atoms disturb the vibrations of its neighbour; therefore the space upon the screen C C_1, which lies parallel to the slit *a c*, and between the perpendiculars *a* C and *c* C_1, appears fully illuminated.

But this is not the case with the portions of the screen beyond C and C_1. The wave-systems originating in the ether particles between *a* and *c* spread themselves also to the right and left, and the lines *a a′*, *c c′* represent such

8

rays, which fall in a slanting direction upon the screen. As the outside rays *c c'* and *a a'* have no longer travelled equal distances, the ether particles at *a'* and *c'* are not necessarily in the same phase. The difference in the phase of their vibration evidently depends upon the difference *a d*, or the length of their paths, and this is the greater the more obliquely the pencil of light falls upon the screen; that is to say, the greater the angle the oblique rays make with the direction *a* C of the incident rays A *a* C. Let us now successively examine the individual instances where the difference *a d'* in the outside rays amounts to 1, 2, 3, 4, etc., half wave-lengths. Let ϕ be the angle which *a a'* makes with *a* C.

When the angle ϕ_1 is so small that the difference *a d'* for the outer ray amounts exactly to *one* half wave-length, then the interference (§ 36) is total for the outer rays *a a'* and *c c'*, but only partial in the rays in their neighbourhood, whilst it is altogether absent in the central rays *b b'*. The collective effect of the individual rays forming the deflected pencil of light consists therefore in a diminution of light, as compared with the direct rays *a* C, C_1 *c*, and this is shown on the screen by a decrease of light on both sides the central bright band C C_1. Calculation shows that the intensity of light in these places amounts to 0·4, as compared with the central band C C_1; if the latter be represented by I, and the former by I_1, then $I_1 = 0·4$ I.

When the angle ϕ is greater, and the difference in the distance of the paths of the two outer rays of light amounts to two halves, that is, to one whole wave-length, we may imagine the oblique rays to be divided into two equal portions by the central ray *b b'*. The difference then in the paths of the rays *b b'* and *a a'*, and also of *c c'* and *b b'*, is a half wave-length; these rays, therefore, produce total interference, and destroy each other. But this is also true of all the individual rays of the first half *a b*, and of the

corresponding rays of the second half *b c*, of the whole pencil of rays *a c*, whence it follows, that all the individual rays between *a a'* and *b b'* mutually destroy one another. The amount of light, therefore, from the complete pencil of rays at the spot where it falls on the screen is absolutely *nil*, and a dark band is the result.

If by an increase in the angle ϕ the difference *a d'* of the paths of the outer rays amounts to three half wave-lengths, the whole pencil may be divided into three equal parts, the outer rays of which, on their way to the screen, differ from one another by half a wave-length. Of these three pencils of rays two completely interfere as described above, and the light they throw on the screen is *nil*. In the third pencil of rays, however, the individual rays, as in the first instance, stand so related to each other that, while the outer rays, which differ a half wave-length, completely destroy each other, the rest do so only partially, and thus a portion of light remains. The collective effect of a ray of light falling so obliquely upon the screen is therefore a bright band, in which, however, the degree of brightness is considerably less than that of the first band, the first band itself being in an equal degree less bright than the central band C C_1. By a simple calculation it can be shown that the brightness I_2 of the place on the screen on which this pencil of rays falls is $\frac{1}{9}$ of I_1, so that the value of I_2 is $I_2 = \frac{1}{9} \times 0{\cdot}4\ I_1 = 0{\cdot}044\ I$.

A pencil of rays falling still more obliquely upon the screen, in which the difference *a d'* in the paths of the outer rays is two whole wave-lengths, may be divided into four equal parts, the outer rays of which differ by half a wave-length. As these individual rays mutually destroy one another, a second dark band appears at the place where they fall upon the screen. With a difference in the outer rays of five half wave-lengths, a pencil of still more slanting rays may be divided into five equal parts, with the result,

that four portions would mutually destroy each other, while the light of the fifth would be so far impaired that the band of light it forms on the screen would be considerably less bright than any of the former bands. In fact, the brightness of this band I_3 is only $\frac{1}{25}$ of I_1, so that $I_3 = \frac{1}{25} \times 0{\cdot}4\ I = 0{\cdot}0016\ I$.

If this reasoning is carried further, it shows that the concurrent effect of the individual rays of a pencil of diffracted light is absolutely to nullify one another, and therefore to produce a dark band on the screen whenever the difference in the distance travelled by the outer rays amounts to an even number of half wave-lengths. But in the intervals between these dark bands, where pencils of light fall in which the distance travelled by the outer rays amounts to an uneven number of half wave-lengths, there is always a portion of light left undestroyed, which produces a bright band, though the intensity of the light in these bands rapidly diminishes as their distance from the central image increases.

If in Fig. 66 a' represents the place in the image where, as by calculation from the central point between C and C_1, the first dark band occurs, then, according to the above, the line $a\,d'$ in the triangle $a\,c\,d'$ represents a wave-length. If this, as is customary, is designated by λ, it follows from the equality of the triangles $a\,c\,d'$ and $a'\,a$ C, the width of the slit $a\,c$ being designated by s, that $C\,a' : a\,a' = \lambda : s$. On account of the comparatively great distance $a\,C = E$ of the screen from the slit, and the small space occupied by the image, it may be assumed, without any material error, that $a\,a' = a\,C = E$; so that $C\,a' : E = \lambda : s$. If the places on the screen where, reckoning from the centre of C and C_1, the second, third, etc., dark bands would fall, are designated successively a_2, a_3, etc., then $C\,a_2 : E = 2\lambda : s$, $C\,a_3 : E = 3\lambda : s$, etc. Whence it appears that the distance of the dark bands from the centre of the diffraction image, as successively calculated,

increases in the proportion of 1, 2, 3, etc., also that the spaces between the dark bands—that is to say, the bright bands—are all of equal breadth, while the central bright band is double the width of the others.

As in red light the wave-length λ is nearly twice as great as in violet, it follows that with red light C a_1, C a_2, C a_3, etc., —in other words, the distance of the dark bands from the middle of the central band,— is nearly twice as great as with violet light. The bright bands are also nearly twice as broad with red as with violet light.

From the equation $C\,a' = \frac{E \cdot \lambda}{s}$ it will be seen that the breadth of the bright bands is in inverse ratio to the width s of the slit. With a slit widening at the rate of 2, 3, 4, . . . the bright bands become narrower at the same rate.

These results deduced from the undulatory theory of light are in complete accordance with observed phenomena. In order, however, to obtain the above quantities with great exactness, it is necessary to employ the most delicate instruments, and to use them with great care and dexterity; the slit B B, for instance, should be provided with a special micrometrical contrivance, whereby the width of opening may be accurately determined to within about $\frac{1}{200}$ of an inch.

The method of measuring wave-lengths is given in Appendix D.

38. Gratings and their Spectra.—The Diffraction Spectrum.

Among the various contrivances which may be substituted for a slit in studying the phenomena of diffraction, the one of most interest is that of a grating. The gratings employed by Fraunhofer consisted either of very fine metal wire stretched at equal distances across a square frame of brass,

or of very fine parallel lines cut by a dividing machine on a gilded glass plate. The process of ruling has now been brought to great perfection, the lines cut by a diamond upon the glass being about an inch in length, and so close together that even in the coarser gratings there are 1,000 to the inch, while in the finer ones there are from 6,000 to 10,000.* The spaces between the lines form so many slits of uniform width, through which the light passes; the finest gratings, therefore, consist of from 6,000 to 10,000 rectangular slits in close proximity, and about one inch in length.

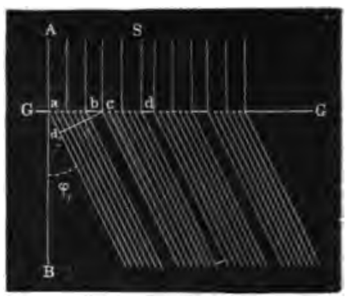
The phenomena of diffraction shown by such a grating when the light falls perpendicularly upon it may be observed in a variety of ways. If the phenomena are to be exhibited on a screen, a sharp image of a slit must first be formed by means of a lens. If a fine grating is then placed immediately in front of the lens, there will appear upon the screen a coloured image consisting of one central white band supported on either side by a succession of *spectra* all placed with the violet end towards the centre and the red outwards. The order of succession in the colours of these spectra is the same as in the prismatic spectrum, but the distribution of the colours is in different proportions. In the grating spectrum, while the two spectra on either side the central line appear isolated upon a black ground, the red end of the second spectrum encroaches on the violet end of the third, so that they partially overlap, and while the two first spectra are short and very brilliant, the succeeding ones gradually increase in length and diminish in brilliancy.

The simplest method of employing gratings is by *direct*

* [Rowland rules gratings on speculum metal now with lines over three inches in length, and at the rate of more than 14,oco lines to the inch, covering six inches in length. He has ruled some gratings at a rate of 42,000 lines to the inch.]

observation. For this purpose a telescope should be directed at some little distance upon a line of light, such as a brightly illuminated slit, and the grating fixed in front of the object glass so that the lines of the grating should be parallel to the line of light. The diffraction image with its spectra will at once be seen. This is very beautifully shown by the slit and collimator lens of an ordinary spectroscope, when removed from the rest of the instrument, if the grating be held between the lens and the eye, with its lines parallel to the slit. If the sun is viewed with an instrument so arranged and the slit almost closed, the most prominent of the Fraunhofer lines may be distinctly seen in the first spectrum, and still more distinctly in the second.

FIG. 67.



Formation of Grating Spectra.

As these diffraction spectra, as we shall presently see, are peculiarly adapted for determining the wave-lengths of the individual colours, we will endeavour to gain some conception of their formation.

Let G G in Fig. 67 represent the horizontal section of a glass grating placed vertically, and let *a b*, *c d*, etc., represent the transparent parts, and *b c*, etc., the parts rendered opaque. If the slit is sufficiently removed from the grating, or if between the slit and the grating a collimating lens is introduced at a suitable distance from the latter, the rays S will fall perpendicularly to the plane of the grating in the horizontal direction A B. It may be assumed that these rays are all of one colour, such as would be given out by a sodium flame, and it may be remarked that all the rays issuing in parallel lines from each individual point in the openings of the gratings become united by the object-glass of

the telescope, or in direct vision by the crystalline lens, and are focussed on the retina of the eye. A careful examination will show that these lenses exert no influence upon the conditions of vibration of the ether molecules lying in the path of a ray of light passing through them; therefore the united pencils of rays we are considering emerge from the lenses unaffected as to their respective wave-lengths.

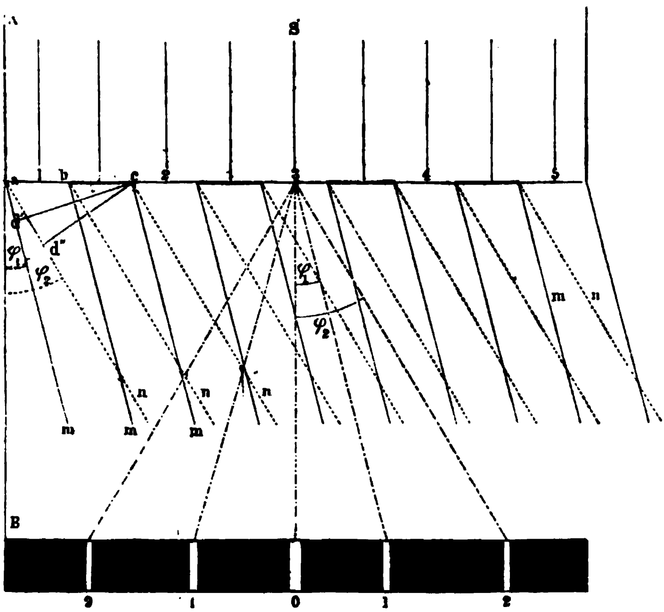
In those pencils of rays which pass through the openings of the grating in a direction perpendicular to it and parallel to A B, a uniform condition of vibration prevails in every section that is parallel to G G. The individual rays have all travelled a uniform distance, and their union produces an increase in the light, so that the centre of the image remains a bright band.

In consequence of the lateral expansion of the waves of light, a countless number of pencils of rays parallel to each other also pass through the grating at various angles to the perpendicular line A B; such a system of rays is represented in Fig. 67 by the angle ϕ_1. Disregarding for the moment the difference in distance of the path of the rays in any individual pencil, let us concentrate our attention on the interference exerted by the individual pencils of rays on one another as they pass through the grating. If from the first outside ray c of the second pencil of rays $c\,d$ we let fall a perpendicular $c\,d_1$ upon the first outside ray a of the first pencil of rays $a\,b$, then $a\,d_1$ is the difference in the distance travelled by the first two pencils; and if the apertures are assumed to be of uniform width, it will also be the difference in the distance travelled by any other two neighbouring pencils. If the difference $a\,b_1$ amounts to a *whole* wave-length, then the waves of the individual pencils pursue their course undisturbed, and where their waves unite produce a greater intensity in the light.

The same is true of other systems of parallel pencils

whenever the angle of deviation ϕ_2 formed with the line of incidence A B is such as to cause any two neighbouring pencils of rays to differ in respect of the distance they have travelled by *two or more whole* wave-lengths. In all such cases the pencils of rays which are in unison assist each other in their effect, and where they unite increase the intensity of the light. In Fig. 68 two such systems are represented in

FIG. 68.



Pencils of Rays in their Passage through Gratings.

their passage through five grating apertures. The first system *m* drawn in continuous lines is deflected to the amount of the angle ϕ_1, and the difference *a d'* in the distance traversed between any two of the neighbouring pencils is assumed to be *a whole* wave-length. The second system *n* drawn in dotted lines is deflected to the amount of the angle ϕ_2, and the difference *a d''* of the distances travelled by any two of

the neighbouring pencils amounts to *two whole* wave-lengths. The union of all the pencils which fall upon the grating in a perpendicular direction parallel with A B produces at O a *middle* bright band—yellow if the light of sodium be employed. The union of the first deflected pencil *m* produces a *lateral* bright band at 1, while the second pencil of rays *n* produces a second lateral band still further removed at 2, and so on. The corresponding systems of rays deflected at similar angles in the opposite direction, and not represented in the drawing, give rise in the same manner to the bright bands 1 and 2 to the left of O.

A very different course is pursued by such systems of rays as, passing in a parallel direction through the grating, are deflected at such an angle that the neighbouring pencils do not differ in wave-length by either one whole or by any number of whole wave-lengths. If we take, for instance, a grating of 1,000 lines or 1,000 apertures, and suppose the angle of diffraction ϕ is such that the difference in the distance traversed by the first and second pencils is $1 + \frac{1}{1000}$ wave-lengths, then the difference between the first and the third pencils will be $2 + \frac{2}{1000}$ wave-lengths, and so on; but the difference between the first and the 501st pencil will be $500 + \frac{1}{2}$ wave-length. This last pencil of rays will therefore be in an opposite phase of vibration to the first one; in a similar manner the 502nd will be in an opposite phase to the 2nd, the 503rd to the 3rd, and so forth up to the 1,000th, which will be in an opposite phase to the 500th. All these individual pencils will therefore interfere completely, and destroy each other. If by a somewhat larger angle of diffraction ϕ the difference between the first and the second pencil is $1 + \frac{1}{100}$ wave-lengths, then on reaching the 51st pencil the difference between it and the first pencil will be $50 + \frac{50}{100}$ or $50 + \frac{1}{2}$ wave-length, in which case the 51st pencil will interfere with the 1st, the 52nd with the 2nd, and so forth,

so that, as before, at the point of union each individual pencil will destroy the other.

It is, moreover, evident that if the angle of diffraction is such that the component rays forming each *individual* pencil destroy each other, the combined effect of two such pencils can produce no light. The dark bands which are present in the diffraction image when only one aperture is in use (§ 37) must therefore remain dark when several such apertures are employed in juxtaposition. In such a case it may, however, happen that one or other of the pairs of rays supposed to form a bright line is annihilated on the way; for each pencil of rays, which would in other conditions unite to form this bright line, carries in itself the germs of destruction. A closer investigation shows that the dark bands seen in spectra of the first order—bright bands formed by *one* slit—augment in number as the apertures in the grating increase, so that when the grating is very closely ruled the remaining bright bands are very narrow, and the dark intervening spaces become in proportion more extended.

A spectrum of this kind formed by such a grating is shown in Fig. 69, the light employed being homogeneous—red in this instance. In the centre of the image appears a red band O Ȯ, the image of the slit, and on either side, at a distance corresponding to *one whole* wave-length, is a narrow red line *R'*, upon a perfectly black background, doubtless the remnant of the first spectrum of the first class, which would have been produced by a single slit. As the grating is composed of a vast number of slits, the brilliancy of this first red line *R'* is considerably greater than with a single slit. Beyond this again, at double the distance from O O, at the spot corresponding to *two whole* wave-lengths, on either side is a second bright red line *R''*, and further still, at distances increasing in the same proportion, is seen a third red line R''', and a fourth, etc.

If the *homogeneous* light is *violet*, besides the central violet line O O, there will appear on either side, at distances corresponding to the shorter wave-lengths of violet light, the violet lines V′, V″, V‴, etc. If *yellow* homogeneous light is employed, such as the flame of sodium, then at distances corresponding to its wave-length there will appear yellow lines which will fall between V′ and R′, between V″ and R″, and V‴ and R‴.

If white light passes through such a grating, then each of its component colours, at places where the differences in the distances they have travelled amounts to a whole wave-length, forms a bright line, so that with the infinite gradation in the wave-lengths of the various colours, the lines follow

FIG. 69.

Grating Spectrum of Homogeneous Light.

one another in an unbroken succession, and produce a coloured band which, beginning with violet, passes through all the well-known colours of the spectrum, indigo, light blue, greenish blue, green, yellow, orange, finishing with red; while, owing to the overlapping of all these colours on the central band O O, this portion appears white.

In this way not only is the first spectrum V′ R′ (Fig. 70) formed, but on either side, at equal distances from O O, the other spectra V″ R″, V‴ R‴, etc., in all of which the violet end lies towards the centre, while the red end is turned outwards. The order of succession in the colours is precisely the same in these spectra as in a spectrum formed by a prism, but the distribution is proportionally different, for in

the grating spectra the position of the colours is accurately determined by their wave-lengths, and, as already pointed out, while the first spectrum V′ R′ stands isolated upon a black ground, the red of the second spectrum V″ R″ is overlapped by the violet of the third spectrum V‴ R‴. If in the incident light certain rays are missing, their absence will necessarily cause a gap in the grating spectra; thus in the solar spectrum as obtained from a grating not finer than from 200 to 300 lines to the inch, the Fraunhofer lines are distinctly visible.

Glass gratings consisting of from 3,000 to 6,000 lines to the inch, and even of 100,000 lines to the inch, can be

FIG. 70.

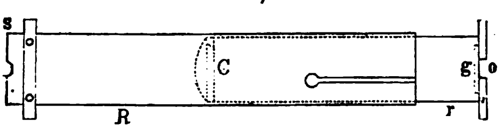
Grating Spectrum.

obtained from Nobert, but their costliness precludes their general use. Gratings of equal delicacy have, however, been produced by Rutherfurd, of New York, so well known for his labours in celestial photography. With a machine of his own construction he ruled lines on glass, which he afterwards silvered. The light *reflected* from the engraved surface of this metallic grating produces diffraction spectra of great purity, and they are formed in the same manner as the spectra are formed by the passage of light *through* the glass gratings. These gratings unfortunately only find their way by the munificence of the constructor into the hands of a limited number of observers. It must therefore be regarded as a laudable undertaking that the attempt has been made of late by one or two physicists to reproduce by

photography on glass the most perfect of Nobert's gratings. The greatest success in this direction has been attained by Lord Rayleigh, who succeeded in producing a good photographic copy of Nobert's glass gratings of 3,000 and 6,000 lines to the inch. He has been able from these copies to make a number of reproductions, which in respect of the purity and brilliancy of their spectra do not leave much to be desired. Lord Rayleigh has published the methods he employed, and his experience gives us reason to hope that gratings as fine as from 10,000 to 12,000 lines to the inch may yet be copied, and multiplied by this process.

For the purpose of merely gaining acquaintance with the action of the grating and the appearance of grating spectra, which are known as *diffraction spectra* in contradistinction to

FIG. 71.



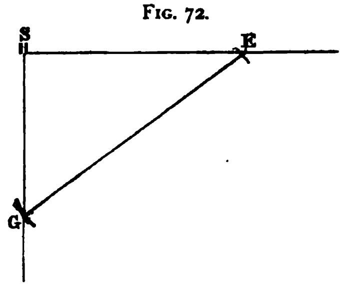
Pocket Diffraction Spectroscope.

the prismatic or refraction spectra, the instrument perhaps best adapted to general use is the pocket diffraction spectroscope shown in Fig. 71. It consists of a tube R, with an adjustable slit S, and an inner sliding tube *r*, carrying a small collimating lens C; *g* is a grating photographed on glass. If the slit is directed towards the sky and the tube *r* drawn out till a sharp image of the slit is formed by the lens C, and if the lines of the grating are parallel to the slit, three very beautiful diffraction spectra will appear on both sides of the white central line. When the light is sufficiently strong some of the Fraunhofer lines may readily be recognised.

[In a note on page 118 we stated that Professor Rowland had ruled gratings on large surfaces and with very close lines. He has further modified the apparatus necessary

for studying diffraction phenomena by ruling lines on concave spherical surfaces of polished spectrum metal. The radii of these surfaces vary from about 4 feet to 40 feet. The great advantage of this plan is that for observing spectra neither telescope nor collimating lens is required, only a slit and an eye-piece. Mathematical calculation shows if *r* be the radius of curvature of the mirror, and if a circle be described with this radius as a diameter, that if a bright point be placed anywhere on the circumference of this circle, the focus of the reflected image of that point will also lie on the circumference. If then the slit be placed on the circle, the focus of all parts of the different spectra will also lie on the circumference. To obtain a spectrum which is normal* in a plane tangent to the circle, Professor Rowland places the observing screen, or eye-piece, in the axis of the mirror, and at the distance of its radius, and causes the slit to approach the grating, at the same time making it travel along the circle. This he effects by the artifice shown in Fig. 72.

FIG. 72.



S G and E G are two bars placed accurately at right angles to one another. At S is the slit which is fixed, and the beam of light falls along S G on to G, the grating. The grating is attached to a bar E G, and E G is made equal to the radius of curvature of G. At the other end is E, an eye-piece (or a photographic plate). The axis of the grating also lies along G E; G E slides along S E and G S. Now some part of the spectrum will always fall in

* [By a normal spectrum we mean a spectrum in which the distances apart of the different rays when falling on a screen or drawn as in a map are exactly proportional to the differences of their wave-length.]

the direction G E, and will therefore always be in focus, since G E is the radius of curvature of the mirror, and S lies on the circumference of the circle. For as G S E is a right angle, a circle described with G E as diameter will always pass through S. By this plan the wave-lengths at any part of the spectra can be at once compared without error for a considerable distance on each side of E by merely measuring the distances from E of the rays whose wave-lengths are to be compared. A further advantage is that as E G is invariable in length, the scale of wave-lengths is always the same. The wave-lengths can be measured by photographing the spectrum, or by a micrometer eye-piece.]

39. Measurement of Wave-Lengths by means of the Diffraction Spectrum.

The determination of the wave-lengths according to the method described in Appendix D, by the illumination of a single fine slit, is subject to this inconvenience, that there is no means of ascertaining the exact colour of the light employed, nor of determining its position in the solar spectrum. This is not the case with the diffraction spectra, in which not only is the distribution of the colours in exact accordance with the wave-lengths,* but the presence of the Fraunhofer lines affords the means of accurately measuring the wave-lengths of each colour.

From Fig. 68 it will be evident that if the line *a c* comprising the breadth of one aperture in the grating *a b*, and the neighbouring space *b c*, be represented by *b*, and the angle of

* [This is true for a small portion of the spectrum when the grating is in the position indicated above. A comparison of wave-lengths is made by taking the difference between the sines of the angles of incidence and diffraction. Thus when one diffracted ray is normal to the grating, the wave-lengths of any other rays not differing considerably from it may be directly compared by measuring either their angles of deviation from it or the tangents of the same, since sines, tangents, and arcs of small angles are practically equal.]

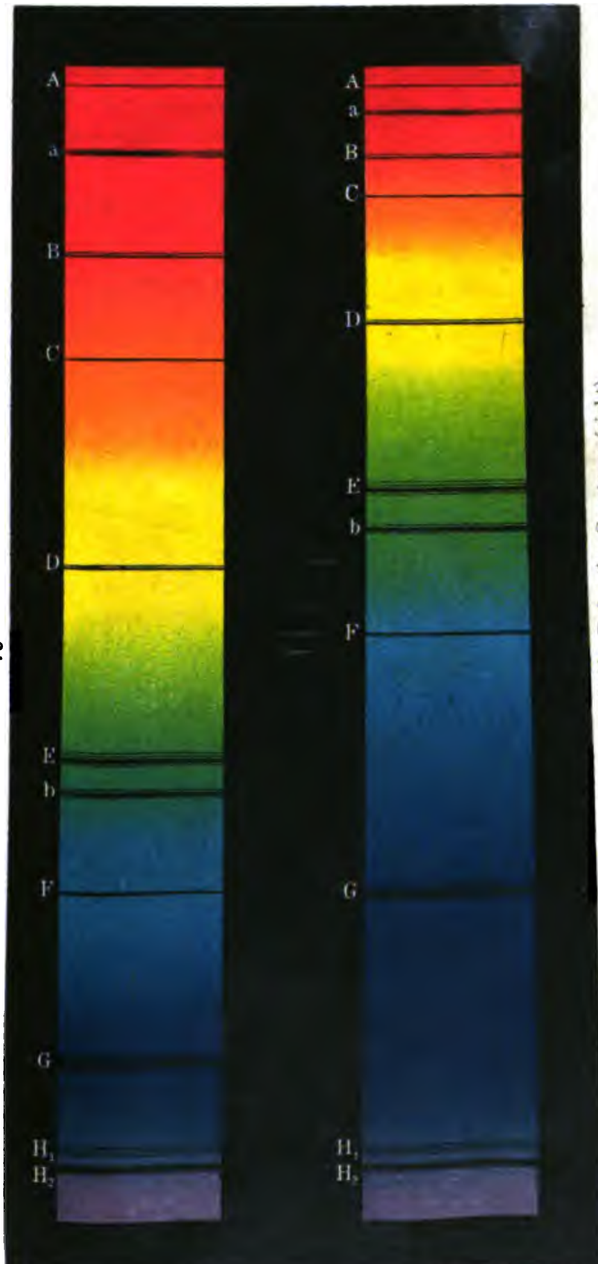


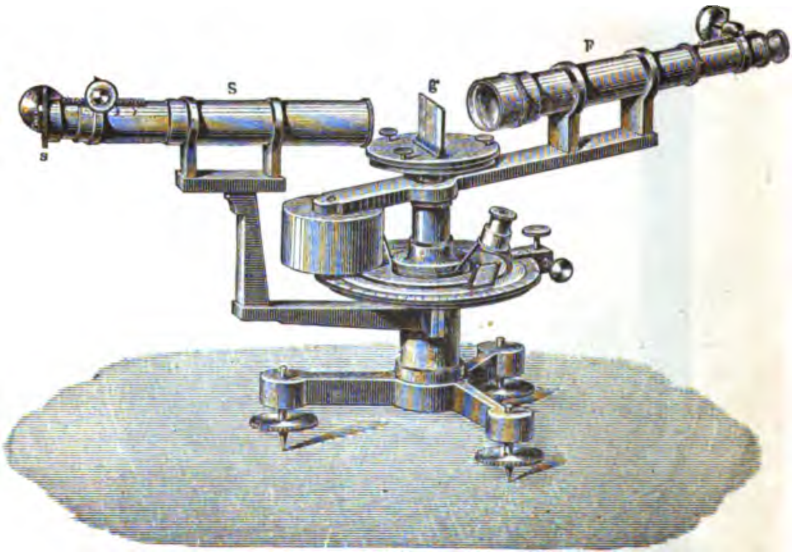
FIG. 73.

Diffraction Spectrum (left); Refraction Spectrum (right).

the other side of the middle line, a test is thereby furnished for the accuracy of the angle measured. Accuracy may be further insured by extending these measures to the second and third bright lines, and thus obtaining the values of the angles ϕ_2 and ϕ_3.

To determine the wave-length of any Fraunhofer line sunlight must be directed on to the slit by means of a heliostat, and the telescope moved angularly from the direction of the

Fig. 74.



Spectrometer.

incident rays, until the cross-wire cuts the line in question either in the first or second spectrum; the arc traversed by the telescope gives the required angle ϕ_1 or ϕ_2.

In this manner the wave-lengths of all the most important Fraunhofer lines have been accurately determined, first by Fraunhofer and subsequently by Ditscheiner, Van der Willigen, Mascart, Bernard, and notably by Ångström. The following table gives the wave-lengths of the chief of

these lines according to Ångström's measures, including some slight corrections which he subsequently added :—

Fraunhofer Lines.	Ten Millionths of a Millimetre.	Fraunhofer Lines.	Ten Millionths of a Millimetre.
A	7604·00	b_1	5183·0
a	7185·00	b_2	5172·0
B	6867·00	b_3	5168·0
C	6562·01	b_4	5166·7
D_1	5895·0 } 5892·12	F	4860·72
D_2	5889·0 }	G	4307·25
E	5269·13	*h*	4101·2
		H_1	3968·01
		H_2	3933·00

These researches for determining the wave-lengths of the various colours of the solar spectrum have been carried still further by the labours of Mascart, Ketteler, Müller, Thalén, and others, by whom the light emitted by various terrestrial elements when in a state of incandescence has been examined, and the wave-length determined by direct observation of the diffraction spectrum.

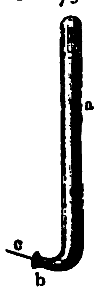
By the use of gratings we thus possess the means of separating composite light into its component parts without causing it to undergo refraction by a prism. Diffraction spectra are therefore free from the defects of the faulty distribution of the rays due to the glass or the liquid of which the prism is composed. Ångström applied with justice the term *Normal Solar Spectrum* to the spectrum he mapped, in which every ray is noted in its absolute wave-length.

40. Various Methods for Exhibiting the Spectra of Terrestrial Substances.

The spectra of incandescent *solid* and *liquid* bodies are *continuous*, and resemble each other so closely, that only in a very few instances can they be distinguished; spectra of

this kind are, therefore, not suitable for the recognition of a substance, though they may authorize the conclusion, that the substance is either in a solid or liquid state. Only *discontinuous* spectra, consisting of coloured lines, or bands, which are obtained from a *gas* or *vapour*, are sufficiently characteristic to show the chemical constitution of the vapours by which the light is emitted. It is on this account that spectrum analysis deals pre-eminently with the investigation of vapour spectra, and that for the examination of a substance which does not exist in nature in the form of gas or vapour, the first step is to place it in this condition.

FIG. 75.



Mitscherlich's Spectrum Wick.

The temperature at which substances are volatilized varies greatly; while the heat of an ordinary spirit lamp is sufficient for many, such as potassium and sodium, for others, especially the heavy metals and their compounds, the great heat of the electric spark (§ 5) or of the electric arc (§ 8) is requisite. For most practical purposes, however, as in laboratory work, the temperature of the non-luminous flame of the Bunsen burner is sufficient, as it will readily volatilize the following metals, potassium, sodium, lithium, strontium, calcium, barium, cæsium, rubidium, copper, manganese, thallium, and indium, especially if in combination with chlorine.

To distinguish the spectra obtained by these various processes they are termed (*a*) *Flame spectra*, (*b*) *Spark spectra*, (*c*) *Arc spectra*.

(*a*) *Flame Spectra*.

In using the Bunsen burner (Fig. 2), the air is first shut off from below, and a pure continuous spectrum of the luminous flame obtained by an accurate adjustment of the telescope and a careful setting of the slit. To prevent

flickering, the lower part of the flame is surrounded by a hollow cone of sheet iron; by the introduction of atmospheric air the flame is then rendered non-luminous, and only the upper very hot point of the flame made use of, into which the substances to be tested are introduced upon the end of an exceedingly fine platinum wire bent into a loop, this metal being unaffected by this high temperature. Upon the appearance of the spectrum the focus of the telescope is adjusted, and the slit narrowed sufficiently to ensure the sharp definition of the bright coloured lines. The drawback to this method is the short duration of the spectrum. To obtain one of greater permanency Mitscherlich devised the following expedient. A solution of the substance to be examined is introduced into a small glass vessel *a* (Fig. 75), closed at the top and bent round at the lower end, which terminates in a narrow tube *b*. In this opening is placed a bundle of very fine platinum wire *c*, tightly held together by a platinum wire, and secured into the tube by the bent position of the wires. By capillary attraction, the liquid is continually drawn through the opening to the place of volatilization by the platinum wick. A series of such tubes may be ranged round the circumference of a revolving table *d* (Fig. 76), so that the platinum wick of any one of them can be brought at will into the flame of the Bunsen burner *h*, placed near the edge of the table. An addition of acetate of ammonia to the solution assists the capillary action of the platinum wick. When properly adjusted in the flame this artifice allows the spectrum to be continuously observed for upwards of two hours.

The platinum wick has of late been superseded by thin rods of gas-coke or asbestos, which give a still more lasting spectrum. Before being impregnated with the chlorides to be volatilized, they are purified by being boiled in acid.

(*b*) *Spark Spectra.*

When the heat of the Bunsen burner is not sufficient to volatilize the substance to be investigated, recourse must be had to the voltaic arc or to the induction coil, the latter being preferable on account of its greater facility of management. The apparatus is employed in the usual manner by introducing the substance to be examined, whether solid or in

FIG. 76.

Mitscherlich's Apparatus for Permanent Spectra.

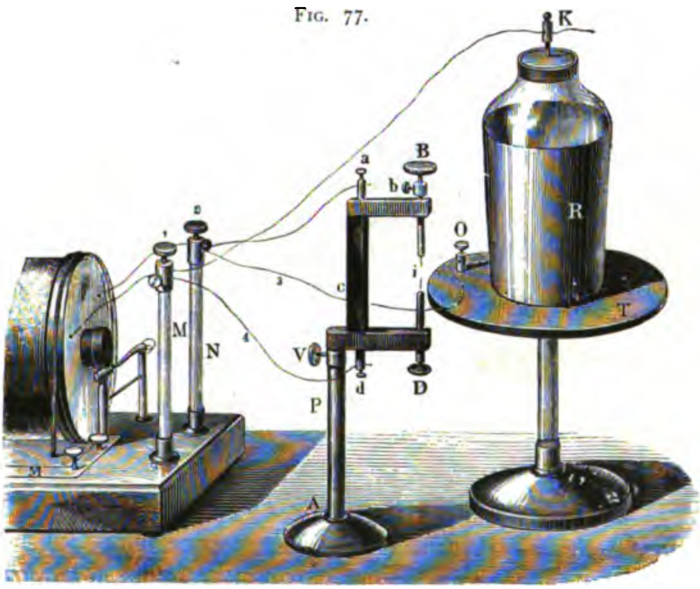
a liquid form, between the platinum spark terminals. The spectrum of the spark is examined, or when this heat is insufficient, the spark is intensified by the introduction of a condenser.

The effect of this method in general is to produce two spectra, superposed, one of the gas through which the spark passes, and the other of the substance volatilized by the heat of the spark. If electrodes of different metals are employed, and the spark is always allowed to pass through

the same gas, the spectrum of the luminous gas appears as if it were a background upon which the more intense spectra of the metals stand out in relief.

The method of applying a Leyden jar (condenser) for intensifying the spark is shown in Fig. 77. M is the end of the induction coil, supplied with electricity from a powerful Bunsen battery of from six to eight elements

FIG. 77.



Intensifying the Electric Discharge by a Leyden Jar.

(Fig. 10). The extremities of the coil are fastened into the insulated binding screws 1 and 2. From the first (1) of these pass two wires, one (4) to the binding screw *d*, and the other to the knob K, in connection with the inner coating of the intensifying jar R; from the second (2) also pass two wires, one to the binding screw *a*, and the other (3) to O, where it is connected by the copper disc T with the outer coating of R. B and D are wire

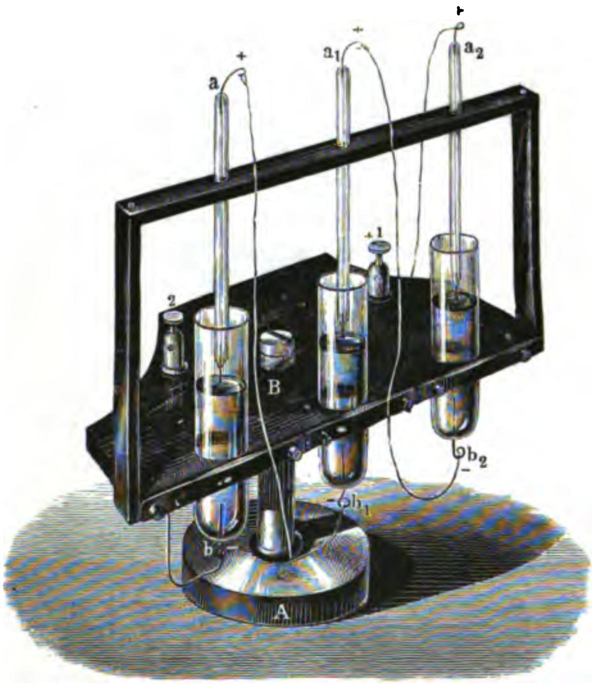
holders for the reception of the metals to be examined, or for the insertion of platinum wires, the ends of which may be smeared with the substances to be investigated. The upper metallic arm *a b* B is insulated from the lower arm *d* D by the intervening piece of ebonite, so that the passage of the opposite electricities accumulated in 1 and 2 can take place only through the wires B and D at *i*, and the spark can only pass when the quantity of electricity accumulated in the jar R is of such an intensity as to enable the discharge to break through the stratum of air between the wires B and D. Sparks produced in this way are shorter than those not intensified, but far more powerful, and are capable of volatilizing every metal.

The most convenient contrivance for the examination of the spectra of liquids and of substances in a state of solution is that devised by Séguin, of Grenoble. It consists of several glass vessels, b, b_1, b_2 (Fig. 78), five or six inches in height, and rather more than an inch in width, inserted in the small table A B; these vessels are fused at one end, while at the other they are closed by corks. A platinum wire fused into the lower end of the vessels, and projecting into the inside, places the liquids they contain in connection with the *negative* pole of the induction coil, while a second platinum wire, fused into the narrow glass tubes a, a_1, a_2, passes through the corks from above, and projecting one-twentieth of an inch from the small tubes, remains some tenth of an inch distant from the surface of the liquids. By connecting the binding screws 1, 2 on one side with the induction coil, and on the other side, as shown in the figure, with the platinum wire b of the first vessel, and a_2 of the last vessel, and by placing the other wires in connection, a with b_1, a_1 with b_2, etc., the current may be made to pass through all the liquids, and by the passage of the spark between the upper platinum wires a, a_1, a_2, and the liquids,

the substances in solution may be volatilized, and their various spectra obtained.

When the induction coil is so regulated that the interruption of the current and consequent passage of sparks takes place in rapid succession, the spectrum remains almost free from disturbance, and the apparatus works

FIG. 78.

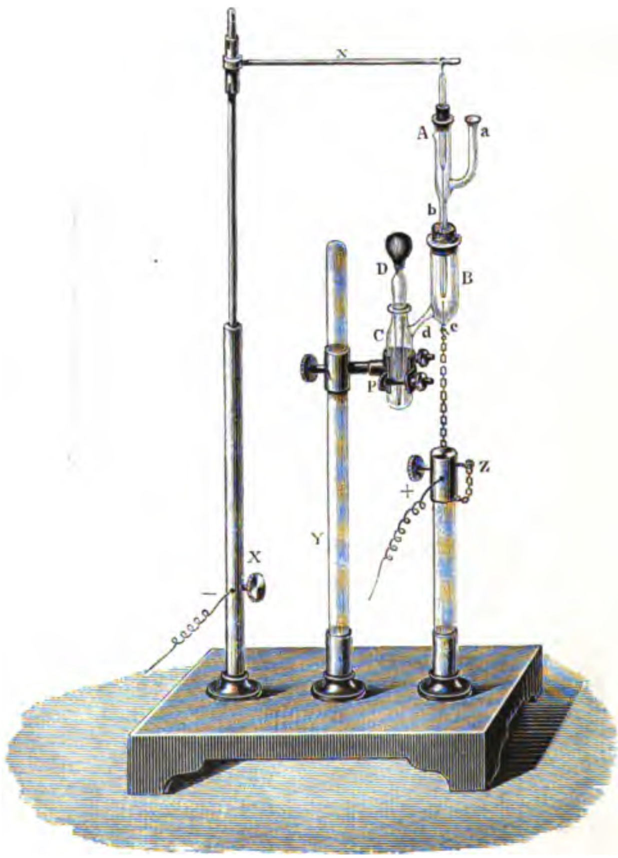


The Becquerel-Ruhmkorff Apparatus.

for hours together like an intense heat-lamp constantly fed with the substances to be investigated. As, however, by the rapid succession of sparks the liquids in the smaller glass tubes often become heated, wider tubes should be employed when the apparatus is to be used for many consecutive hours.

But even this arrangement has the disadvantage that when the spark is too short part of it is hidden by the convexity of the liquid, and when it is too long it branches

FIG. 79.

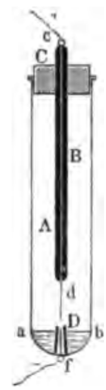


The Fulgurator.

out in various directions, and fails to pass in front of the slit. These evils have been remedied to some extent by a contrivance termed a *Fulgurator*. It consists mainly of a glass tube *b* (Fig. 79) opening above into a somewhat larger

receiver A, to which is attached a lateral feeding tube *a*. The platinum wire by which the receiver A is suspended to the brass rod *x* passes through the cork A into the tube *b*, and terminates at its mouth. The tube *b* passes through the cork into the glass vessel B below, which is connected at one side by the glass arm *d* with the reservoir C, and which receives the platinum wire *c* at its lower end. The reservoir C is provided with a small pipette terminating in an india-rubber ball, by which any liquid collected in the vessel may be drawn off and reintroduced at *a*. The lower platinum wire *c* inserted within B is connected by a brass chain to the clamp Z, while the upper one *b* in connection through *x* with the clamp X is capable of being raised or lowered, so that the distance between the ends of the wires within the tube B may be under control.

FIG. 80.



Simple Arrangement for the Continuous Observation of the Spectra of Vapours.

When the clamps Z and X are put in communication with the poles of the induction coil, the spark passes between *c* and *b*; in consequence of this action the liquid to be examined flows drop by drop from A into B, where it encounters the spark and becomes converted into glowing vapour. The liquid which escapes volatilization collects in B, whence it passes through *d* into the reservoir C.

By this arrangement the spectrum of a substance may be examined with the greatest ease by the hour together, while the liquid that is unconsumed is preserved from contamination and ready for further use.

A simpler, and in most cases an equally efficacious contrivance, has since been devised. It consists of a glass tube A Fig. 80) about four inches high, and about half an inch in diameter, closed at one end, and secured at the

other by the cork C, through which the capillary tube B is introduced. In this tube a platinum wire is fused, forming a positive electrode, which terminates above in a small loop, and extends below in a straight line to within a short distance of the lower negative electrode *f*. The latter is fused into the end of the tube A, and is covered with a small conical glass cap projecting about a fiftieth of an inch beyond *f*.

When in use the liquid to be examined is poured into the tube A, so that the level *a b* does not reach over the cap D; indeed, it is better that it should not rise more than half the height of D. By capillary attraction the liquid rises to the top of the cone, where it collects drop by drop, and is volatilized as the spark passes from *d* to *f*.

Many advantages are secured by this simple fulgurator: the spectrum remains a considerable time; observation is never hindered by the convexity of the liquid; nothing is lost of the solution that has been examined; while from the simplicity of the contrivance a great variety of solutions may be prepared and kept ready for use.

For these experiments, solutions of the various metallic compounds of chlorine in pure water are the most suitable; when in a concentrated form they produce spectra of great intensity, but weak solutions will give spectra that are easily recognized. The spark is coloured more or less intensely according to the nature of the metal held in solution. The following metals give great brilliancy to it: chloride of sodium (yellow), chloride of strontium (red), chloride of calcium (orange), chloride of magnesium (green), chloride of copper (greenish-blue), chloride of zinc (blue); but various other compounds of barium, potassium, antimony, manganese, silver, uranium, iron, etc., give also very remarkable coloured light and corresponding characteristic spectra. One advantage attendant upon this method of investigation

is the absence of any spectrum from the platinum wires, inasmuch as the heat of the spark is insufficient to completely volatilize this metal.

The following arrangement was adopted by Bunsen for subjecting fluids to the action of the induction coil. Stick charcoal, such as is commonly used by artists, is rendered a conductor of electricity by being subjected for many hours to a white heat whilst surrounded with powdered charcoal in a covered porcelain crucible. This in its turn is inserted in a fire-clay crucible. The charcoal sticks are then pointed, and the conical ends sawn off with a watchmaker's saw. Five hundred such cones can easily be prepared in a day, so that there is no difficulty in having a good store of them for a series of observations. The charcoal points must next be purified from all foreign substances, such as silica, magnesia, manganese, iron, potassium, sodium, and lithium. To accomplish this they are repeatedly boiled in a platinum vessel, a thousand at a time: first in hydrofluoric acid, then in concentrated sulphuric acid, afterwards in concentrated nitric acid, and finally in hydrochloric acid; between each process the cones are boiled and rinsed in water, to remove all trace of the solutions. A small hole, corresponding to the platinum electrode, is next drilled into the base of the cones, and they are ready for use. For each experiment a fresh cone must be placed upon the electrode, and saturated with the requisite solution by means of a fine capillary tube slowly heated over a gas-flame. The charcoal cone weighs about 0·015 gramme, and can take up more than its own weight of fluid. The spectra produced last long, so that it is only at rare intervals that the cones require to be refilled. When saturated with solutions chemically pure, and therefore producing spectra of undoubted purity, the cones, as well as the solutions, may be stored away in glass bottles, and labelled, in order to serve for comparison spectra.

When using a *single* prism spectroscope, as may often be the case in laboratory work, and when a spark spectrum is produced by aid of a condenser, the induction current usually employed is of such a strength that the striking distance between blunt platinum wires should be from $\frac{1}{8}$ to $\frac{3}{4}$ of an inch, the spark passing in a horizontal direction before a perpendicular slit. To shield the slit from the injurious effect of the acid which might be splashed upon it, it is closely covered with a plate of mica, which from time to time is removed and cleansed.

(*c*) *Arc Spectra.*

The intense heat produced by the voltaic arc (§ 8) is needed only in the rare instances when in scientific research the spectrum of a heavy metal is required in its most complete form, or when a record of all its lines is to be taken by photography. For the production of the voltaic arc a powerful battery of at least fifty elements is necessary, with a lamp having a regulator (§ 9), for maintaining a continuous arc. When the carbons are pure the spectrum of the arc is continuous,* and so brilliant as to overpower the spectrum lines of substances vaporized in the flame. To diminish the excess of light, the carbon points must be kept as far apart as possible without breaking the arc. By this means the central part of the flame becomes sufficiently reduced in brilliancy to allow of the spectrum of the substance brought under its influence to be observed.

If the carbon points are replaced by metallic conductors, a very brilliant spectrum is formed in the centre of the arc, exhibiting all the characteristic lines of the metals. These

* [This is not the case. The carbons are never pure, and there is always a spectrum of carbon vapour present.]

lines occupy in the spectroscope the same position* as when the spectrum is produced by the induction spark, with the difference that while the latter is intermittent owing to the interrupted discharge, the glowing vapour in the arc of flame remains unchanged so long as the arc remains unbroken.

The voltaic arc, when formed from metallic poles, is of very unequal density; for the vapour which keeps forming at each pole is subject to oxidation and dispersion through currents of air, and thus becomes less dense in the centre of the arc than at the poles, and this difference is the more apparent the further the poles are separated. When the poles are of different metals, the arc exhibits three different spectra; the upper portion of the flame displays the vapour of the metal of the upper pole, the lower portion exhibits that of the lower pole, while in the middle the vapours of both metals are combined. If, therefore, the arc is observed in its vertical position through a vertical slit, these three spectra are received simultaneously. It is further to be remarked that the vapours are denser within the arc than at the outer edges.

It had previously been noticed that the spectra formed from metallic electrodes vaporized in the heat of the spark were composed of lines varying greatly in length, but we are indebted to Mr. Lockyer for the careful study of this phenomenon and for the discovery of its importance. In order to observe these short and long lines in all parts of the arc, and especially for the registration of their position with respect to the poles by means of photography, the lamp must be so placed that the arc is formed horizontally, and the image thrown by a lens in a direction coincident with the slit. It is evident that the image of the slit

* [The arc and ordinary spark spectra exhibit variations, and an air-break in the circuit when a condenser is used causes still greater variations to be exhibited.]

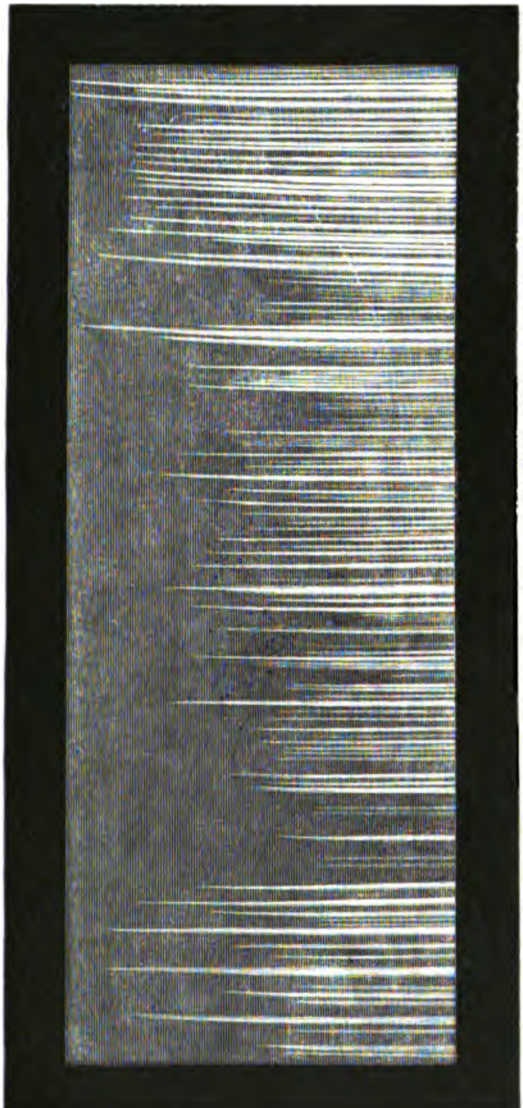
will coincide in the spectroscope with that of a section of the arc; if, therefore, vapours of various kinds are formed round the poles, each producing a separate spectrum, they may be individually examined, if the slit is placed perpendicularly to the length of the arc—that is to say, vertically, and may be traced from pole to pole by moving the slit along the line of the arc. The spectrum of the central and denser portion contains the most lines, while that of the outer portion shows but few.

Fig. 81 exhibits the spectrum of iron in the neighbourhood of the *F* line, as photographed in this manner by Lockyer. The iron employed was not pure; the lower portion of the photograph is the spectrum of the axis of the arc where the vapour was most dense; it exhibits all the lines which this portion of the arc can produce for itself alone. The longer lines reach to the extreme edge of the arc as far as the vapour extended, and diminish in breadth in proportion as the vapour loses in density.

(*d*) *Observation of Gas-Spectra.*

In investigating the spectra of gases Plücker's tubes are usually employed, the capillary portion being placed parallel, and close to the slit. On the passage of the current, the enclosed gas becomes intensely luminous in the narrow part of the tube, and a distinct spectrum is formed. In the use of these tubes, however, a special mercury exhausting-pump is requisite. The plan adopted by Ångström was to allow the electric discharge from a Leyden jar or induction coil to pass between two points of the same metal enclosed in the glass tube containing the gas. In this case the gas or metallic spectrum is more or less brilliant according to the distance of the points one from the other. The spectrum of gas should therefore be observed in the middle between the metal points, where it is most distinctly

Fig. 81.



Copy of a Photograph of the Spectrum of Iron.

marked, and most easily distinguished from the discontinuous spectrum of the metal.

For observing the spectra of gases at atmospheric pressure, a convenient method, adopted by Dr. Huggins, is to cause the spark to pass between wires sealed in a glass tube, which is drawn into an open capillary at one end, and at the other is connected with the vessel in which the gas is slowly produced. The glass tube should be cut away in front of the wires, the edges ground flat, and a small plate of glass held air-tight over the opening by elastic bands, an arrangement which permits of any deposit on the inside of the tube being easily removed. By this method fresh portions of gas are constantly exposed to the spark, which is of importance when some of the compound gases are under examination, and some sources of impurity, which are possible when the gas is collected, are avoided.

FIG. 82.

Salet's Tube.

From the mode in which the Plücker tubes are constructed, it is extremely difficult to obtain the gases with which they are filled in a condition of absolute purity, and the same difficulty is experienced with regard to the electrodes attached to them, whether of platinum or aluminium. Both these inconveniences combine to render the spectrum of the gas often impure or confused by the presence of other spectra. To obviate these evils, Salet has substituted for the electrodes two bands of metal, surrounding the wide ends of the tubes. The tubes are constructed of glass capable of resisting a temperature of red heat; and while being subjected to such a temperature, they are cleansed by a stream of pure and dry oxygen being passed through before receiving the gas to be ex-

amined. This eliminates the spectra arising from the decomposition of carbon by the spark.

A tube of this description is shown in Fig. 82; it is placed in communication with the induction coil by the metal bands *a* and *b*, and produces the effect of two Leyden jars, the knobs of which are turned towards each other. The metal bands represent the outer covering, while the enclosed gas forms the inner lining. Every interruption that takes place in the current through the bands excites a corresponding current in the interior of the tube, and when connected with a powerful induction coil, or with a Holtz machine, the electric action is so strong as to cause the centre of the tube to be intensely luminous.

41. Designation and Delineation of the Lines of the Spectrum.

Not only the number of the spectrum lines of a substance, but also their relative intensities, require careful attention. As the brilliancy of the lines increases with the temperature, so, as a rule, it is those lines which are particularly prominent at a high degree of heat that are the first to appear at a low temperature. These prominent lines, therefore, are the most suited for the recognition of a substance, and on this ground are called the *characteristic* lines. Such lines, according to their degree of brightness, are designated in each substance by the letters of the Greek alphabet, α, β, γ, δ, etc., being affixed to the chemical sign denoting the substance. The spectrum of potassium (Fig. 83, No. 1) has two characteristic lines, one red and one violet; the former, as the most intense, is therefore designated **K**α, the latter **K**β. The brilliant red line of lithium (No. 3) is designated **Li**α, the fainter orange line **Li**β; the characteristic lines of the

FIG. 83

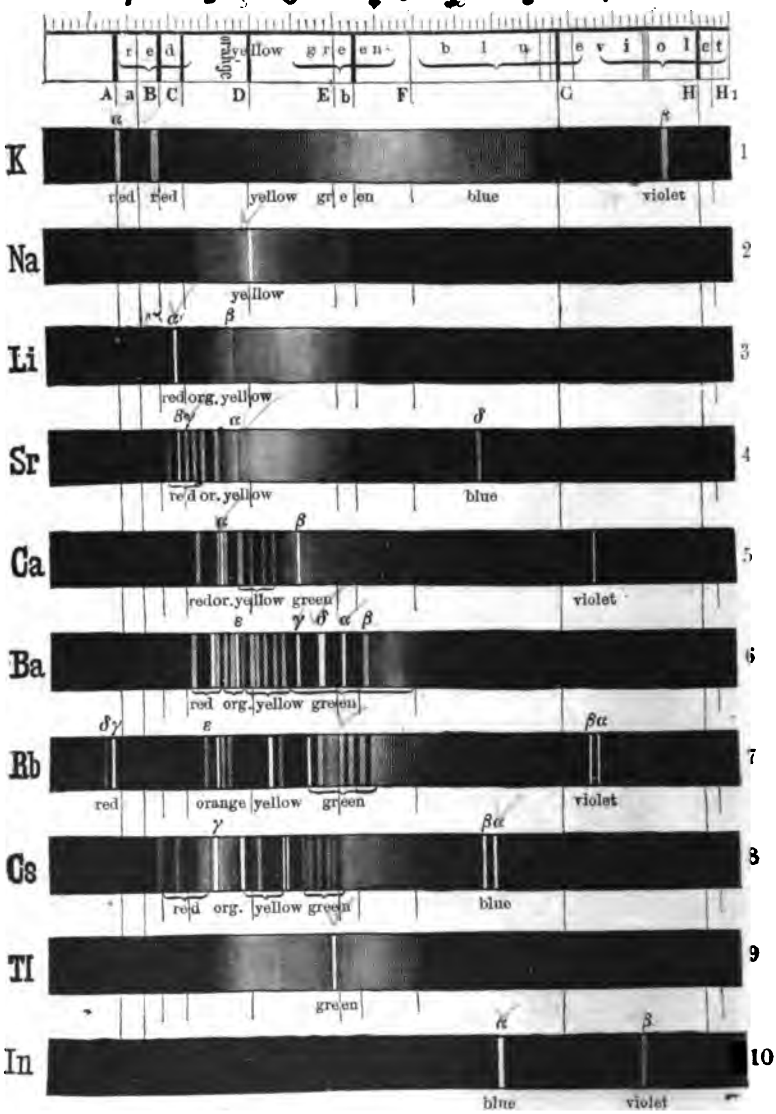


Table of Spectra according to Kirchhoff and Bunsen.

spectrum of barium (No. 6) are in the green; those of cæsium (No. 8), **Cs**α and **Cs**β, are blue; those of rubidium (No. 7), **Rb**α, **Rb**β, violet, and **Rb**γ **Rb**δ, dark red; the most intense line of hydrogen gas (Plate XIV., No. 6) is red, and is designated Hα, the greenish-blue line nearly equal to it in brightness Hβ, and the much fainter violet line Hγ, etc.

The table in Fig. 83 exhibits the spectra observed by Kirchhoff and Bunsen as follows: 1, Potassium; 2, Sodium; 3, Lithium; 4, Strontium; 5, Calcium; 6, Barium; 7, Rubidium; 8, Cæsium; 9, Thallium; 10, Indium, collated for easy comparison, with a statement of the colour of the individual lines, and a scale for determining their relative distances. The colours marked above No. 1 represent the solar spectrum with the most prominent of the Fraunhofer lines.

As the spectra of the same element differ greatly in various spectroscopes owing to the variation in the indices of refraction of the component prisms through which the relative position of the lines is considerably affected, it naturally follows that no drawing, however accurate, of any portion of a spectrum can be of real value unless accompanied by a scale by which the true position of the lines may be identified by their wave-lengths, and thus brought into comparison with the results of other instruments. The method of construction of such a scale is given in Appendix E.

FIG. 84.—Diagram of the Spectrum of Chloride of Strontium according to Bunsen.

A spectrum may either be delineated, as in Fig. 83, by a

careful representation of all the lines and bands in accordance with their position, breadth, and degree of brightness, or according to Bunsen's much simpler plan (Appendix F), as shown in Fig. 84, of drawing the scale of the instrument for every spectrum, and recording on it the various lines and bands with respect to their position, breadth, and brightness by means of short strokes. The proportionate length of these strokes (ordinate) exhibits the relative degree of brightness.

Fig. 85.—Spectrum of the Star Bonner Durchmesser + 2° No. 4709.

This plan is specially adapted to spectra consisting of isolated bands of various brightness. An example of this is given in Fig. 85, where the remarkable variations in brightness of the lines in the spectrum of the star Schjell. No. 273 (Bonner Durch. + 2° No. 4709) are graphically represented by Dr. H. C. Vogel. The *rising* of the curve denotes an *increase* in brightness, while the numbers correspond with the scale of the spectroscope.

42. The Solar Spectrum of Kirchhoff and the Spectra of Metals.

Kirchhoff and Hofmann mapped the spectra of a number of metals in order to compare their bright lines with the dark lines of the solar spectrum. We shall have occasion again to refer to these maps when discussing the physical constitution of the sun; for the present we shall content ourselves with remarking that the solar

spectrum forms the basis in their construction, as the lines of the metals were introduced when the two spectra were visible at the same time in the spectroscope. The Fraunhofer lines, therefore, serve as guides for the position of the bright lines of the metal.

With the same object in view, Dr. Huggins recorded the spectra as given by the spark of twenty-four metals, to which he added those of hydrogen, carbonic acid, nitrogen, oxygen, and the air. The basis of these maps was the spectrum of bright lines given by air, which was divided into two portions, one from *a* to F of the Fraunhofer lines, and the other from F to H.

Both of these maps are alike subject to the disadvantage that, being constructed upon an arbitrary prismatic scale, comparison with other results is rendered extremely difficult. For this reason the tables themselves are not in full agreement, as Kirchhoff, in order to preserve the minimum of deviation, often changed the position of the prisms, while Huggins allowed them to remain undisturbed.

The following is a list of the elements included in Kirchhoff's maps :

1 Sodium	9 Strontium	17 Antimony	25 Aluminium
2 Calcium	10 Cadmium	18 Arsenic	26 Lead
3 Barium	11 Nickel	19 Cerium	27 Silver
4 Magnesium	12 Cobalt	20 Lanthanium	28 Gold
5 Iron	13 Potassium	21 Didymium	29 Ruthenium
6 Copper	14 Rubidium	22 Mercury	30 Iridium
7 Zinc	15 Lithium	23 Silicon	31 Platinum
8 Chromium	16 Tin	24 Beryllium	32 Palladium

Huggins' maps contain the spectrum lines of the following metals:

1 Sodium	7 Thallium	13 Antimony	19 Lead
2 Potassium	8 Silver	14 Gold	20 Zinc
3 Calcium	9 Tellurium	15 Bismuth	21 Chromium
4 Barium	10 Tin	16 Mercury	22 Asmium
5 Strontium	11 Iron	17 Cobalt	23 Palladium
6 Manganese	12 Cadmium	18 Arsenic	24 Platinum

It has already been shown (§ 27) that the relative position of the spectrum lines of a substance is dependent upon the number of the prisms and their refractive power. A record, therefore, of the position of any lines upon an arbitrary scale can lead to no conclusion as to the nature of the lines, or the rays producing them, unless certain conditions are also recorded by which the divisions of the scale may be converted into wave-lengths (Appendix E). Such a record presupposes that the wave-lengths have already been determined for a great number of the Fraunhofer lines, from which a wave-length curve may be constructed for any instrument provided with a scale or micrometer.

Fraunhofer commenced this work by determining the wave-lengths of certain prominent dark lines of the solar spectrum. Subsequent observers, Ditscheiner, Van der Willigen, Mascart, and Gibbs, perfected his methods, and extended their measurements to a far greater number of lines. But it was reserved to Ångström of Upsala to complete the task, in the accomplishment of which he expended a care and devotion which has secured for his work the stamp of completeness, and rendered it for all time a model of scientific research.

In his "Recherches sur le spectre solaire; spectre normal du Soleil," Ångström first laid down in wave-lengths the visible solar spectrum. By means of a grating he and Thalén determined the wave-lengths of nearly 1000 lines to within the *ten millionth of a millimetre*, and added, by interpolation, the lines not directly observed, finding by calculation their relative position with respect to those that had been measured. By a simple formula these wave-lengths taken in air may be reduced to their values in vacuo. Ångström's maps are given in Plates VIII., IX., X., and XI., and his catalogue of the wave-lengths of the lines of the solar spectrum will be found in Appendix G.

43. Other Maps of the Solar Spectrum.

Since the construction of Kirchhoff's and Ångström's maps of the solar spectrum, so many additional lines have been rendered visible through improvements in the spectroscope, that a reference to the maps for the identification of a line is no longer easy. A reconstruction of the maps to include all the new lines became, therefore, a matter of importance. This work was first undertaken by Lockyer, and subsequently by Vogel of the Potsdam Observatory. The first named has mapped the region 380 to 400 millionths of a millimetre, and the last named commenced with the portion between *b* and E. Vogel has completed most of the spectrum lying between the wave-lengths 480 and 540 millionths of a millimetre; but the work will not be extended to the less refrangible parts of the spectrum until the portion already completed has been compared with the spectrum of various parts of the solar surface.

44. Wave-lengths of Lines in the Spectra of Metals by Thalén.

The registration of the spectrum lines, according to their wave-length, which gives such value to Ångström's map of the solar spectrum, has since been extended by Thalén to the spectra of most of the metals. Wherever practicable the lines were compared direct with the solar spectrum, in other cases a wave-length curve was employed (Appendix E), and the wave-length of each line found by interpolation from the observed place in the prismatic spectrum. Of the forty-five metals examined, twenty-three were in a solid state, in as pure a condition as possible, namely, potassium, sodium, aluminium, magnesium, iron, cobalt, nickel, zinc, cadmium, lead, thallium, bismuth, copper, mercury, silver, gold, tin, platinum, palladium, osmium, antimony, tellurium, and

indium. They were volatilized by the induction spark of a powerful Ruhmkorff coil, and, when possible, were used as electrodes. The remaining twenty-two metals were examined in chemical combinations, chiefly as chlorides, namely: lithium, cæsium, rubidium, barium, strontium, calcium, beryllium, zirconia, erbium, yttrium, thorium, manganese, chromium, cerium, didymium, lanthanum, uranium, titanium, wolframium, molybdenum, vanadium, and arsenic. The lines registered were restricted to such as could be readily seen, and undoubtedly belonged to the metal under examination.

The scale gives the wave-lengths in hundred-thousandths of a millimetre; and the addition of two decimals enables the wave-length of a line to be ascertained with tolerable certainty to within the ten-millionth of a millimetre. The *short* lines which make their appearance as needle points at the edge of the spectrum, when the vapour is much increased in volume, are indicated in the maps by very short strokes.

Thalén's catalogue of the wave-length of these lines is given in Appendix H.

45. Spectrum Maps by Lecocq de Boisbaudran.

Another arduous undertaking, recently accomplished by Lecocq de Boisbaudran, has been the careful examination of the spectra of a number of substances needed in laboratory work, with the accurate measurement of their lines. The spectra were produced either by a Bunsen burner or blowpipe, or by a spark about an inch in length, without the use of a condenser. The measurements were made with a photographed and movable scale such as is described in § 27. The results of this comprehensive work are given in the "Spectres lumineux," in which the spectra are admirably reproduced in twenty-eight plates. The lines are

represented according to the scale of the spectroscope employed, and also in a millimetre scale by which the wave-lengths may be read off. In one of the plates a wave-length curve is given, on which the numbers on the micrometer scale may be converted into wave-lengths to the ten-millionths of a millimetre. The letterpress accompanying each spectrum descriptive of the position, wave-length, breadth, and intensity of the lines, together with a specific statement of the characteristic lines of every spectrum, must be of the highest value to all workers in the field of spectrum analysis.

The investigations include the spectra of the spark at both high and low tension, when passing between platinum poles, or between a platinum wire and hydrochloric acid. The spectra of the following substances, both as they appeared from a gas-flame and from a spark, were also examined in their different compounds: potassium, sodium, lithium, rubidium, cæsium, barium, strontium, calcium, magnesium, aluminium, manganese, iron, cobalt, nickel, cadmium, thallium, indium, tin, bismuth, lead, antimony, copper, silver, mercury, gold, platinum, boracic acid, and phosphoretted hydrogen. The emissive and absorptive spectra of erbium and didymium were also investigated.

The new metal, *gallium*, discovered by Lecocq de Boisbaudran during his spectroscopic researches, has a spectrum of two bright lines in the violet, the wave-lengths of which are 417·0 and 403·1 millionths of a millimetre; the former Ga α is very intense, and must be regarded as the most characteristic line of the metal; the other line Ga β is obviously less bright.

46. Watts' Index of Spectra.

For all who are engaged in spectrum analysis a compact summary of the lines of individual elements is of the greatest

assistance, especially if accompanied by drawings, in which, by the help of tables, every line may be identified by its position, intensity, and wave-length. Such a work, under the title of "Index of Spectra," has been produced by W. Marshall Watts, in which all the lines measured up to the date of its publication in the spectra of the elements are catalogued, and illustrated by seventy-eight lithographed drawings.

In an alphabetically arranged list, each element is accompanied by the names of the observers by whom the lines have been measured, together with the publications in which their observations have appeared. In the catalogue of the lines the number of the scale under which a line appears in the spectrum is given in the first column, and opposite this number the wave-length as computed by various observers. The last column contains details as to the brightness of the lines (see Appendix J).

47. Plurality of Spectra.

Bunsen and Kirchhoff have shown that the degree of heat in which a substance is volatilized has no influence on the position of the coloured lines of the spectrum, but that it affects considerably their number and brightness. As the brightness increases with the temperature, it often happens that bright lines appear in the spectrum at a high temperature which were scarcely to be seen, or indeed were even invisible, at a lower one. The spectrum of thallium consists of a single bright green line when volatilized in a Bunsen burner; but if the spark is allowed to pass between two thallium wires, many other lines become visible, among them a set of violet-coloured bands at some distance from the bright green line. Lithium in a moderate temperature gives only one magnificent red line; at a higher temperature a faint orange line makes its appearance, and with the intense heat of the voltaic arc, there is a further addition

of a bright blue band. The principal red line (Kα) of potassium can be made to appear and disappear, according as the temperature is increased or diminished. The spectrum of sodium, if produced by a Bunsen burner, consists of a close pair of orange lines. If the temperature of the flame is raised, the brilliancy of this pair is immediately augmented, and the number of coloured lines is much increased. If the sodium vapour is raised to the temperature of 2500° C. (4532° Fahr.), the bright lines become so numerous that the spectrum becomes practically continuous. The sodium flame becomes whiter, and contains rays of every degree of refrangibility.

Plücker and Hittorf obtained similar results in their researches on the spectra of luminous gases and vapours. They proved the existence of two different spectra (of the first and the second order) in hydrogen, nitrogen, oxygen, phosphorus, sulphur, selenium, etc. The spectrum of the first order is a continuous one, with shaded bands *; that of the second order consists of narrow bright lines on a dark background: the former appears with an electric discharge of moderate tension, while the latter belongs to a high temperature, such as can be produced in Geissler tubes by a high tension spark.

Notwithstanding this, Ångström emphatically stated that his observations had not convinced him that a variety of spectra were produced by the same gas, but that a gas, when pure, had only *one* spectrum, and that a spectrum of lines. Doubtless the spectrum was subject to modifications; with an increase of temperature many more lines might appear, and a change take place in their relative brightness, but the fundamental character of the spectrum would remain unaltered. Ångström admitted that with an intermittent current and an increasing tension of the gas, the lines might

* [These bands are resolvable into lines.]

occasionally spread out, and even extend so far as to meet and produce a continuous spectrum ; but even in this case it could not be said that a new spectrum was formed.

Upon the death of Ångström, Thalén still maintained this opinion, and to substances volatilized by the spark never ascribed other than a spectrum of lines. A variety of spectra displayed by the same substance is attributed by Thalén to the effect of allotropic modification. From a spectroscopic point of view, such spectra present all the characteristics of a compound body, which is being decomposed by the spark. The two spectra obtained from nitrogen by Plücker are, according to Ångström and Thalén, identical, inasmuch as the spectrum of the second order is only that of air, exclusive of the lines due to oxygen and hydrogen.

The conclusions arrived at by Wüllner are of a completely opposite character. After going through a series of investigations on oxygen, hydrogen, and nitrogen, he found that different spectra were produced according as the density varied.

The following remarkable phenomena are exhibited by hydrogen with a Ruhmkorff's large induction coil when worked by a battery of six of Grove's cells, and with the occasional introduction of a Leyden jar (Fig. 77). When the pressure to which the gas is subjected is much less than one-twentieth of an inch of mercury, the spectrum is discontinuous, consisting of six groups of extremely bright lines in the green. When the density of the gas increases, there appears *temporarily*, when using a moderately strong induction current, a *banded spectrum*, I. order (Fig. 86, H. I.), which, however, on the pressure of the gas amounting to one-twentieth of an inch, soon changes into the *line spectrum* designated by Plücker as II. order (Fig. 86, H. II.), and consisting of the three lines Hα (vivid red), Hβ (bright green-blue), and Hγ (blue-violet, and

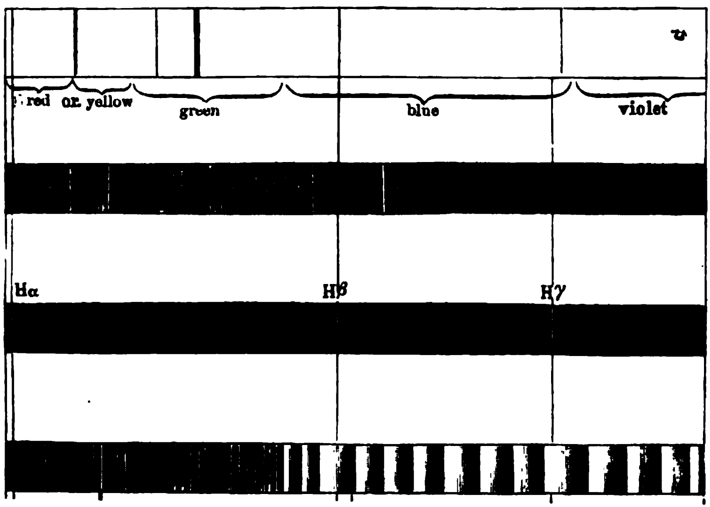
fainter than the others). When the pressure of the gas exceeds that of one-tenth of an inch, a bright line appears in the red and in two places in the green, and with an increase of pressure the spectrum assumes more and more the character of a banded spectrum (I. order) extending from orange to blue, but still crossed by a series of bright lines between Hα and Hβ. Up to a pressure of eight inches

FIG. 86.

H I.

H II.

N I.



Spectra of the Various Orders.

this spectrum retains its full brilliancy, but as the pressure increases to sixteen inches it gradually loses in intensity, without its general character being essentially altered, excepting that the individual lines, as was observed by Plücker, begin to widen.

If the pressure is still further increased, the spectrum again becomes brighter, the yellow and the orange gradually reappear, the line Hα remains still very bright, but is somewhat indistinct at the edges. From this line, however, a

completely continuous spectrum without bands extends from the orange to the violet, and is brightest where the line Hβ was situated. With a further increase of density the brightness of the spectrum is throughout much increased; under a pressure of twenty-nine inches, there is still a faint maximum of light perceptible at the spot Hα, which at a pressure of thirty-nine inches almost ceases to be noticeable.

The spectrum is then completely continuous between Hα *and* Hβ, like that of an incandescent solid body, only the brightness is somewhat differently distributed. The temperature of the tube is now raised so high by the heated gas that the bright orange pair of lines of sodium appear, due to the vapour of sodium given out by the glass. With a pressure of forty-eight inches the whole of the continuous spectrum is really dazzling. Under a pressure of fifty-two inches the electric discharge from the jar may still be made to pass through the tube, though it will only take place in flashes.

The changes, therefore, through which the spectrum of hydrogen successively passes when the density is gradually increased from the minimum up to the maximum pressure at which the induction current ceases to pass are as follows: 1, the spectrum of six lines in the green; 2, the temporary banded spectrum (I. order); 3, the spectrum of three lines (II. order); 4, the more permanent and complete band spectrum (I. order); 5, the pure *continuous* spectrum.

That the fluted band spectrum (Fig. 86, H. I.) differs essentially from the unshaded continuous spectrum is shown by Wüllner's observations with the Leyden jar. When the condenser was introduced the fluted spectrum was not visible, but by an increase of pressure the spectrum of the three lines, Hα, Hβ, Hγ, passed at once by a widening of the lines into the unshaded continuous spectrum; it

is therefore incorrect to describe a banded spectrum as a continuous spectrum of I. order, and also to speak of two distinct continuous spectra.

Oxygen exhibits nearly the same phenomena. Under slight pressure there first appears a spectrum of bands; as the pressure increases, this spectrum gives place to what Plücker has designated a spectrum of lines, which loses in brilliancy as the density of the gas increases, till at a pressure of eight inches it is scarcely visible. The brightness then augments, and at the same time there appears as a background an unshaded pure continuous spectrum, which becomes so brilliant in the red and yellow as to incorporate the lines of the other spectrum, which are no longer distinguished by their greater brightness.

In nitrogen, the change from the banded spectrum (I. order) to the pure continuous spectrum is very distinctly marked, since at a certain density of the gas the spectrum of bands I. order (Fig. 86, N. 1) disappears, and is replaced by the spectrum of lines (II. order) upon a dark background; it is not till afterwards that the background becomes quite continuous and luminous.

By a number of careful experiments Professor Schuster has shown that pure nitrogen produces but *one* spectrum,* and that a spectrum of lines and that the bands of flutings forming the spectrum of the first order are produced by the oxidation of the nitrogen under the influence of the electric spark.

The spectrum of oxygen was also made by Schuster the subject of careful investigation. To secure himself from any deceptive appearances resulting from want of purity, he arranged that the gas should be throughout enclosed in glass, so that it should never come in contact with grease or indiarubber. Any possible influence from the electrodes

* [This statement Professor Schuster subsequently withdrew.]

was eliminated by varying the metals employed, while contamination from the walls of the tubes was obviated by repeating the experiments in wide glass vessels. The results are in unison with those obtained by Wüllner. In the wider part of the tube there almost always appeared at first a continuous spectrum. When the spark passes under atmospheric pressure, it may be so weakened by placing the carbon points near the limit of disruption, that a continuous spectrum is formed instead of a linear one. The second spectrum is the ordinary linear spectrum given by a powerful spark under ordinary pressure. Schuster's experiments thus confirmed the compound spectrum of lines first observed by Plücker. It consists of one red, two green, and one blue line. It is always seen upon the continuous spectrum formed at a low tension, and appears first in the capillary part of the tube. By increased attenuation of the gas the continuous spectrum disappears, and the lines alone remain visible. If, at the same condition of rarefaction, a spark of higher tension is allowed to pass, the ordinary spectrum of lines is seen, and the composite one entirely disappears. The spectrum of bands described by Wüllner, as formed from the negative pole, was observed by Schuster as also a fourth spectrum.

In denying to hydrogen a plurality of spectra, Salet is quite in accord with Ångström. The latter, in dealing with experiments that seemed to oppose his views, lays great stress upon the difficulty of preserving highly rarefied gas in a state of absolute purity. He mentions an experiment in which the air had been as nearly exhausted as is usually possible from a Geissler tube by a mercury-pump, and yet the following spectra were seen in succession:—the ordinary spectrum of air, the flutings of hydrogen, the spectrum of carbonic oxide, and the spectra of chlorine and sodium. The line spectrum was the only one allowed by Ångström and

Thalén to be characteristic of hydrogen; with increased pressure it passes into a continuous spectrum.

From his experiments, Wüllner, on the contrary, came to the conclusion that the variations in the spectra of simple gases are dependent upon the kind of electric discharge by which they are produced, so that the band spectra are the product of an induction current, and the line spectra that of the electric spark. In some experiments made by Goldstein, however, the spectrum of nitrogen appeared as a banded one when a spark was used, while a Geissler tube, filled with rarefied hydrogen, gave a spectrum of bright lines when heated in a silent current. These and various other experiments led Goldstein to the conclusion that the different spectra were independent of the form in which the electricity was applied. In answer to this Wüllner points out that Goldstein's conclusion is not justified, since wherever a closed electrical circuit is interrupted by sparks, the same effect takes place in any tube that may have been introduced into the circuit, because the rhythm of the discharge is everywhere the same. Wüllner had already made the experiment of allowing the spark to discharge into a tube filled with hydrogen, from the positive electrode alone, so as to lose itself in the lower half of the tube. When examined by a spectroscope the upper half near the spark yielded a spectrum of lines, while the lower half, where the spark had become diffused, produced a spectrum of bands. Wüllner also noticed that sparks, however rapid in succession, could never produce the effect of a continuous discharge, in which case no lines are shown.

During a series of experiments undertaken by Wüllner in March 1873, it was demonstrated that a gap made in a closed induction circuit for the reception of a tube containing rarefied gas did not always elicit sparks, even when the rhythm of the discharge was the same. The occurrence of sparks

depends far more on the density of the enclosed gas and on the length of the gap. As long as the current passes through the rarefied gas without actual sparks, a band spectrum is formed; the moment sparks appear a line spectrum is added.

Wüllner explains this phenomenon by supposing that the spark only causes those molecules to become luminous which lie directly in its path, illuminating, as it were, just one string of molecules. Consequently only the absolute maxima of the emissive power corresponding to the temperature of the spark can show themselves in the spectrum. In the brush discharge from the positive electrode, on the contrary, the whole of the enclosed gas is rendered luminous, and there is, so to speak, a *thicker* luminous layer; light, therefore, of every wave-length for which the emissive power at a certain temperature is everywhere the same, will be found in the spectrum. But as the luminous gas is always in an extremely rarefied condition, the spectrum must exhibit variation in the emissive power for the different kinds of light, and the spectra will in consequence be fluted, as we find to be the case in a spectrum of bands.

Lockyer regards the plurality of spectra from another point of view. He insists, first of all, that when gas is examined under moderate pressure, and not very high temperature, a simple spectrum of lines is obtained. If the pressure is gradually increased, so as to bring the individual particles nearer together, thus making the gas approach somewhat the condition of a solid body, the spectrum will also become more and more resembling that produced by the latter, until at length it assumes the form of a bright continuous spectrum. If hydrogen, for instance, is taken, and a Sprengel pump is used for three or four hours, the spectrum will be found to consist of only a single line. If the tube is refilled with gas at an ordinary atmospheric

pressure, and that pressure is doubled or increased ten or more times, not only will the green line at first seen become brighter and broader, but several new lines will make their appearance, which will each continue to gain in breadth until their individuality is lost. With a pressure of twenty atmospheres, the spectrum is as completely continuous as if produced by a solid body. Among the spectra of metals there are two forms in which they *approach* to continuity. In some cases, as in the examples given by Lockyer of calcium and aluminium, the continuous spectrum is built up by the widening of the lines, in others by an increase in the number of the lines, a notable instance of which was observed in the spectrum of the iron of the Lenarto meteorite. In explanation of this phenomenon, Lockyer holds that in the line spectrum the active agent is the individual atom, while in the banded spectrum it is the group of atoms or congregation of molecules. A similar view is held by Thalén.

This much seems at present to be established, that among the causes affecting the plurality of spectra must be reckoned the density of the gas, the thickness of the luminous stratum, the strength of the electric current in which the substances are volatilized, together with the kind of electric discharge and the changes of temperature consequently produced. That magnetism also exerts a demonstrable influence upon the formation of spectra was first announced by Trève. Such modifications undoubtedly take place, yet, according to Ångström, "the effect of magnetism is to bring into incandescence irrelevant substances or irrelevant combinations." According to this theory, the action of magnetism in certain cases somewhat resembles that of a condenser when applied to a Ruhmkorff coil: a kind of chemical action is set up, whereby certain combinations are either originated or facilitated, while others are impeded. A Geissler tube between the poles of an electro-magnet gave the ordinary

spectrum of carburetted hydrogen, but apart from the influence of the magnet the hydrogen lines did not appear; the spectrum was that of carbonic oxide. Another tube filled with hydrogen obtained by decomposition of water, and dried by sulphuric acid, gave the two spectra of hydrogen noticed by Plücker, and under the influence of magnetism was seen by Ångström to throw out Wöllner's third spectrum of hydrogen—which Ångström always regarded as the spectrum of sulphur—with the spectrum of carbonic oxide at the poles.

Many more observations, and possibly new methods of investigation, are required before the conditions for the production of a plurality of spectra can be fully ascertained.

48. Ciamician's Investigations on the Influence of Density and Temperature upon the Spectra of the Non-Metallic Elements.

The labours of Ciamician form, as it were, a sequel to those of Wüllner. In studying the spectra of incandescent vapours formed by means of a powerful induction spark, he directed his attention to the effects produced by variations in the density of the gas or vapour, as also by changes in the amount of tension and temperature of the spark.

The changes produced upon the spectra of rarefied gases by increasing pressure showed themselves in an alteration in the relative intensity of the lines, followed by an increase in their breadth, and finally by the formation of a more or less developed continuous spectrum. The group of halogens exhibited many very remarkable points of resemblance in the phenomena of their spectra. For instance, the vapour of bromine in a rarefied state forms a spectrum resembling that of chlorine, the resemblance becoming closer as the rarefaction increases; whereas in a denser condition the

spectrum resembled that of iodine. Inversely iodine only gave a spectrum corresponding to that given by bromine when the vapour of the latter was in a condition of very moderate attenuation; when the vapour of iodine was of but slight density, the resemblance to bromine disappeared, and a relationship to the spectrum of chlorine made itself apparent. In a highly condensed state, however, the vapour of iodine formed a spectrum scarcely bearing any resemblance to the spectra of the other halogens. The various spectra formed by the same substance under different circumstances are termed by Ciamician partial spectra, the concurrence of which constitute the complete spectrum of the element. Examples of such complete spectra, as drawn by Ciamician, are given in Fig. 87, representing the spectra of chlorine, bromine, and iodine; the lines of chlorine, however, which when the vapour is condensed appear shaded off at the edges, are drawn as sharp lines. For the explanation of the bracketed groups of lines marked A', B', etc., we must refer the reader to the original treatise.

As certain lines maintain an unvarying intensity, while others fluctuate with the changes of pressure or temperature, Ciamician regarded the *unchanging* lines as those *characteristic* of the element, and out of these built up a *characteristic spectrum.* Examples of such are given in Fig. 88.

With a moderate temperature *sulphur* yielded the spectrum of the first order described by Plücker and Hittorf, which, upon the temperature being raised or on the introduction of a condenser, was supplanted by a spectrum of the second order as observed by Plücker, Hittorf, and Salet. Upon the temperature being still further raised, Ciamician noticed the gradual suffusion of a continuous glow in the red part of the spectrum, which increased with an increase in the density of the vapour, but never so as to obliterate the lines.

With phosphorus, Ciamician was no more successful

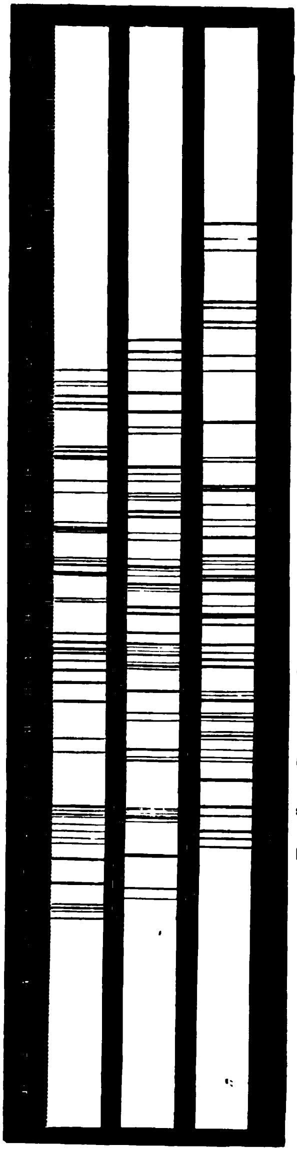


FIG. 87.—Complete Spectra of Chlorine, Bromine, and Iodine.

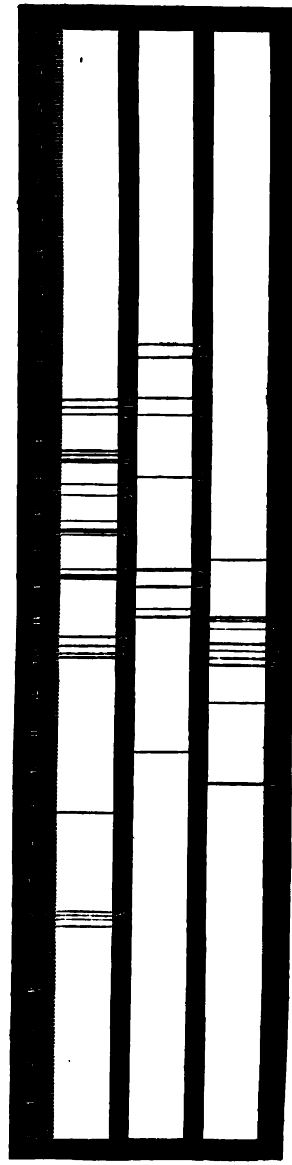


FIG. 88.—Characteristic Spectra of Chlorine, Bromine, and Iodine.

than Salet in procuring a spectrum of the first order, and the spectrum of the second order remained unchanged by an increase in the density of the vapour, the lines remaining sharp, while no trace of a continuous spectrum was visible.

49. Absorption of Light.

Light, in the act of travelling through any medium, invariably suffers loss; it is more or less absorbed by the medium. This absorption varies greatly according to the constitution of the absorptive substance. If a ray of light is allowed to fall upon glass thickly coated with soot, the light, whatever its colour may be, is completely stopped by the soot. In this case the *absorption is total.*

If we allow a ray of light to fall on white glass, it passes through, but we may easily convince ourselves that on emerging it is not so brilliant as before it came in contact with the glass. This is still more evident if the ray passes perpendicularly through a glass vessel with parallel sides filled with water. If the water is only an inch or two deep, a considerable part of the light is absorbed. If the light is white, and therefore composed of all colours, it passes through without undergoing any manifest change in this respect, though the colours have each lost something in an equal proportion. Again, if a smoked or neutral-tinted glass is introduced between the source of light and the spectroscope, it will be seen that the light is diminished along the whole length of the spectrum; that is to say, there has taken place, in contradistinction to what was called above total absorption, a *partial absorption.*

A very different effect is produced when a coloured substance is placed in the path of the rays. If a beam of white light is allowed to fall upon a red glass, all the rays

will be absorbed except the red rays; if upon blue glass,* all light will be absorbed except the blue rays. If both the red and the blue glass are placed in the path of the rays emerging from the prism, then nearly the whole of the spectrum is extinguished. These coloured substances, according to their tint, therefore select and absorb certain colours out of white light. With them a *selective absorption* takes place.

It is thus evident that the phenomena of the emission and absorption of light, diverse as they are, yet offer striking parallels. They may both be either general or selective—that is to say, emitted light may either contain rays of every colour, without a break in the continuity of their order, or consist only of certain selected, isolated colours; and in precisely the same way absorptive substances may either absorb light of every colour, or only light of some particular, selected colour.

For the exhibition of the phenomena of absorption a continuous spectrum must always be first formed upon which the action of the absorptive medium may be shown: the effects produced by an absorptive medium upon a discontinuous spectrum are more complicated, and therefore less easy to follow.

50. Selective Absorption in Solid Bodies.

The power of selective absorption in coloured glass has been already referred to. It is, however, rarely the case that coloured glass is transparent for only one colour; most kinds of glass absorb rays of different colours, and allow others to pass through in very different proportions. The unassisted eye is unable to decide which of the coloured rays are transmitted through a coloured glass; this can only

* [In all blue glass some red rays are transmitted.]

be determined by analyzing the light by a spectroscope or prism.

If light transmitted through coloured glass is examined by a spectroscope, it will be seen that red glass transmits some orange and even some yellow rays, as well as the red, but that it entirely absorbs the green, blue, and violet rays; * blue glass transmits some violet and green rays, besides the blue, but absorbs all the red rays.† If the glasses are superposed, and a gas flame viewed through them, all light seems nearly extinguished; the red glass absorbing the green, blue, and violet rays, and the blue glass absorbing the red rays, the small amount of light remaining causes the gas flame to appear of a dull yellow. A combination of glasses, or indeed any single glass which absorbs all the coloured rays composing white light, is opaque, that is to say, black; no glass is so perfectly transparent that absolutely no light is absorbed.

The striking effects produced by the combination of glasses of various colours are due to selective absorption. Simmler's erythrophytoscope is constructed on this principle, and consists of a pair of spectacles mounted with two different-coloured glasses, one of cobalt blue, and the other of proto-oxide of copper. By this combination the only light transmitted is the extreme red with a few of the blue-green and blue rays. Seen through these spectacles, foliage appears a splendid ruby-red, the clouds purple, the sky blue-violet, and the earth grey-violet. If a glass of cobalt blue is combined with one of dark red, in the manner of Lommel's erythroscope, the leaves and tops of the trees appear bright upon a dark background. With a dark red glass and a bright violet one, a combination termed a Melanoscope, vegetation appears black. Leaves of gelatine impregnated with litmus

* [Ruby glass allows some blue to pass unless it be very deep in colour.] † [See note, p. 172.]

appear whitish at first, but with an increase in the thickness of the coating a blue tint is introduced, whilst a still thicker coating it converts to a purple red. This is an example of entire change of colour with an increase of thickness in the absorptive substance. Very thin leaves of gelatine coloured with litmus offer phenomena of extreme interest when observed with the spectroscope. A single sheet with a very thin coating of the absorptive substance shows a small band near D; an addition of several sheets widens the band and shows another between G and H, while a further increase in the number of sheets produces an absorption of the whole of the spectrum between D and H, until nothing but the red end remains visible. Corresponding to this the thick sheet of gelatine coloured with litmus appears also red to the eye.

In the foregoing examples the phenomenon of absorption is accompanied with a very perceptible change of colour in the transmitted light. This, however, is not always the case. A didymium salt which is nearly colourless, if placed before the slit of a spectroscope, produces several dark lines, some of which are in the places where in the spectrum of incandescent oxide of didymium bright lines occur. Similar absorption bands are formed by gelatine sheets coated with carmine or other colour soluble in water. Didymium salts are not the only ones producing marked absorption bands; they may also be observed in the allied salts of erbium, cerium, lanthanum, as well as in the garnet, chalcolite, uranium, and zirconium salts.

51. Absorption of Light by Liquids.

The absorptive power of coloured liquids is in general much more decided and marked than that of coloured glass.*

* [In reference to this it must be remarked that the colour given to glasses is usually caused by an excessively minute and even

No colouring matter has yet been found which will absorb or transmit only one kind of coloured rays. Even the apparently pure colours of aniline are very far from being really pure. Fuchsin yields a spectrum brilliant in the red and orange which reaches nearly to D. Soluble blue shows a spectrum from the beginning of red almost to D, besides a bright portion in the blue and a faint light in the green. The colours of liquids as seen by white light may be said to be mixed colours; and the absorption which they exercise varies with the strength of the solution.

FIG. 89.

Glass Vessel for Absorbent Vapours.

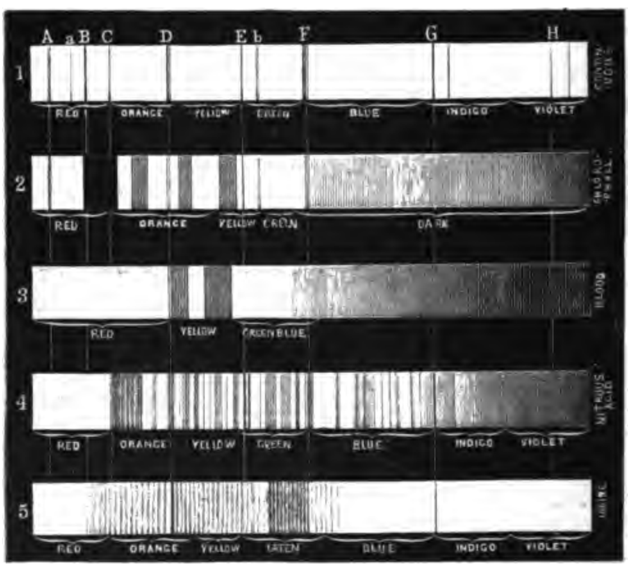
If the phenomena of absorption are to be exhibited by the electric light or the Drummond light, it is desirable to choose those coloured liquids which show their absorption in a very characteristic manner, as, for instance, a solution of chlorophyll—the green colouring matter of leaves—in ether, a solution of the colouring matter of human blood, or a thin layer of potassium permanganate solution in water.

If a continuous spectrum of white light is projected in the usual way, and a glass vessel (Fig. 89) with sides composed of flat plates containing the chlorophyll solution introduced into the path of the rays, the spectrum on the screen will be seen to change. Dark bands (Fig. 90, No. 2) appear in the red, as well as in the yellow, green, and violet; the green chlorophyll solution does not therefore absorb the whole of the red and yellow rays, but only those of a certain wave-length; it exerts the same influence on most of the blue and violet rays, while it transmits

immeasurable film of colouring matter flashed on to one or both surfaces of a white glass plate. The thickness of these films, and not that of the glass, must be compared with solutions as regards intensity of absorption.]

unchanged all the other colours. The spectrum depends greatly upon the strength of the solution: if concentrated, the whole of the blue and green is absorbed, and the light transmitted by the liquid is red. The absorption spectra of a solution of chlorophyll in alcohol according to the varying strength of the solution is given in Fig. 91, after drawings by Pringsheim. The thickness of the

FIG. 90.



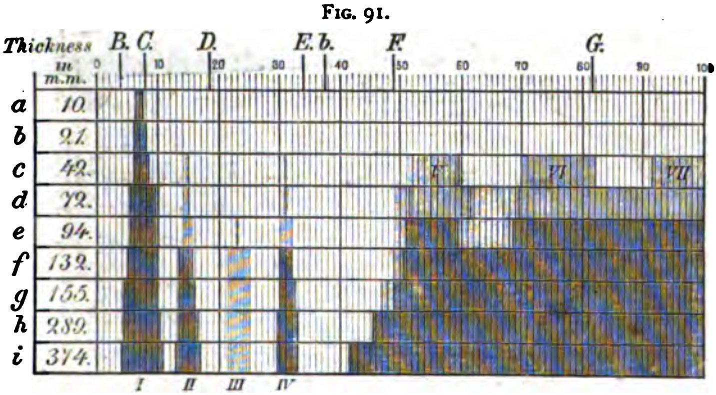
Spectra of Absorbent Substances.

stratum of liquid through which the light passed is given in millimetres. The lowest spectrum *ı* is that most frequently observed; it shows the bands I., II., III., IV., well-defined and clearly separated, while beyond E the absorption is total. Thin layers of very weak solution (*a*, *b*, Fig. 91) show only band I, as a shaded line; with a stronger solution this becomes a dark band; as the strength increases bands V., VI., and VII. are formed in the second half of the spectrum,

and subsequently bands II. and IV. appear almost simultaneously, and are succeeded by band III., as shown in the spectra *e, f, g*. Variations in the order of these phenomena occur, and they probably arise from chemical changes in the substance or from alterations in the intensity of the light.*

The green colour of vegetation is in fact the residue of the solar light after the rays above figured have been absorbed by the chlorophyll held in the cells of the vegetable tissues. The scattered green light reflected from a mass of foliage gives the absorption spectrum of chlorophyll; and

Fig. 91.



Absorbent Spectra of Chlorophyll.

this serves to explain the wonderful effects produced in the appearance of vegetation by combinations of coloured glass.

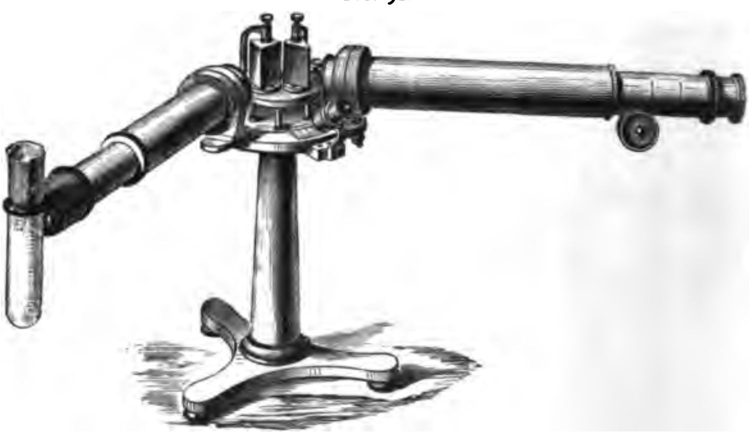
If the experiment is continued with an extremely diluted solution of fresh arterial blood, the red in the spectrum will be intensified, while the blue and the violet will be nearly extinguished. Fig. 90, No. 3, shows in the yellow and

* [The spectrum of chlorophyll has been studied still more recently with great care by Russell, and he has shown that certain of the bands may be made to shift by the addition of acids or alkalies.]

commencement of the green two dark blood bands, with a faint green stripe interposed.

These phenomena are much more evident if they are observed through a spectroscope instead of being projected on a screen; the coloured liquid is then placed immediately in front of the slit, and the spectra viewed direct. It is needful for this purpose to have small glass troughs with parallel sides, similar to the one drawn in Fig. 89,

FIG. 92.



Observations of Absorption.

but Stokes recommends * carefully selected test-tubes, which may be filled with the requisite liquid, and placed, as shown in Fig. 92, close in front of the slit by means of a supporting ring fastened to the end of the spectroscope.

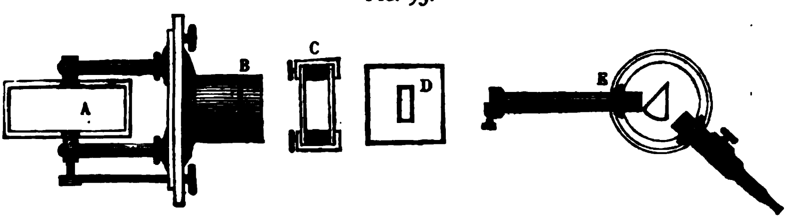
The phenomena of absorption are in general best seen when sunlight is employed, for which purpose the apparatus shown in Fig. 93 is convenient. By means of a heliostat A the solar rays are thrown either direct or through a diaphragm

* [Not in preference to properly constructed cells, but as being more readily obtainable.]

B upon the glass vessel C containing the liquid. Thence they pass through the slit in the screen D to the spectroscope E.

By this method Professor Morton has made a series of investigations upon the various compounds of uranium, and has brought out very strikingly the connection between absorption and fluorescence. Two of the spectra obtained are given in Fig. 94. No. 1 is the spectrum of potassium-urano-fluoride, and No. 2 that of fluoride of uranium. Fig. 95 exhibits other absorption spectra, by the same observer, as follows: No. 1 of ammonium sulphate, No. 2 of double sulphate of ammonium and uranium, No. 3 of magnesium

FIG. 93.



Apparatus for Absorption Investigations.

sulphate, No. 4 of rubidium sulphate, No. 5 of sodium sulphate, and No. 6 of thallium sulphate.

In many cases the smallest changes affecting the liquid—whether from chemical action, or from dilution, or from variations in the thickness of the stratum of the liquid—are accompanied by corresponding changes in the absorption bands, so that it is possible, from the position, breadth, and intensity of the bands, to reason backwards as to the nature and condition of the liquid.

The absorptive action of blood on the spectrum is exceedingly powerful, for it was noticed by Valentin, when experimenting with blood solutions, that the dark bands remained visible when the solution was so weak that the

proportion of blood to water was only 1 to 7004. His observations also went to show that blood, when dried, and in the form of powder, would yield an absorption spectrum, even though the quantity was no more than is sometimes brought into courts of justice as evidence of guilt, and barely suffices to produce a pale yellow solution. In such cases the bands would be very pale, and occasionally there might be even a doubt as to their existence; but in the most extreme instances the corresponding parts of the spectrum, even if somewhat dark, would become perceptibly darker. The subjects of Valentin's experiments were of the following nature: a block of wood, which had served as a dissecting table, but which had lain unused for more than three years in a damp place; a similar piece of wood still in actual use; an old rusty hook, from a butcher's shop, on which meat had been wont to hang; and some blood-stains from one to four years old, adhering to various garments, a playing-card, and a glass tube.

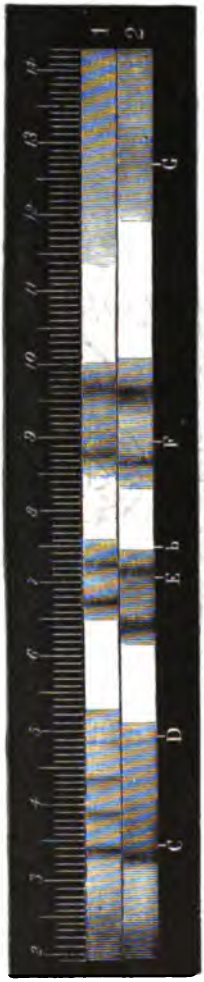
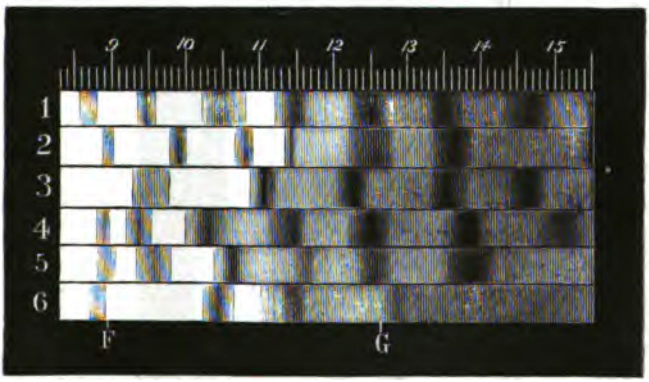


Fig. 94.—Absorption Spectra after Morton.

If, with the same degree of concentration, the stratum of liquid is thickened, the blood bands increase in intensity. A stratum, not more than three-quarters of an inch in thickness, will often produce a decided indication of blood bands, though to the eye no colour is visible by transmitted light, and

only a tinge of yellow by direct illumination. Fig. 96 exhibits the absorption spectra of human blood, as observed by Sorby: No. 1 is that of fresh scarlet blood, No. 2 that of deoxidized blood (cruorin). By the action of an acid the cruorin is converted into hæmatin, which gives a spectrum composed of an entirely different set of bands; and hæmatin can again be oxidized and reduced, until it exhibits the dark bands shown in Nos. 3 and 4.

FIG. 95.



Absorption Spectra after Morton.

Valentin extended his investigations over a number of anodyne tinctures as well as the bright coloured liquids produced by the action of sulphuric acid upon certain poisonous alkaloids, but he failed to discover in any of them a spectrum so specially characteristic as to serve for identification.

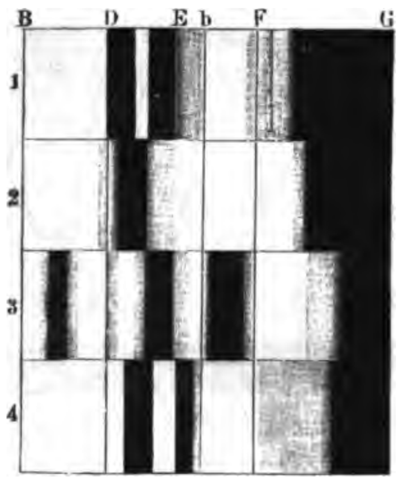
52. THE MICROSPECTROSCOPE.

The object of this instrument is to facilitate the observation of the absorptive phenomena of small solid and liquid bodies, such as are prepared for microscopic examination.

The spectroscopic part of the instrument is so arranged that it can be applied to any microscope by fixing it in the place of the eye piece.

Fig. 97 gives a perspective view of the instrument, and Fig. 98 a section showing the internal construction. The tube A encloses a second tube carrying a direct vision system of five prisms *c*, and an achromatic lens *l* (Fig. 98); by means of a milled head B, with screw motion, this

FIG. 96.



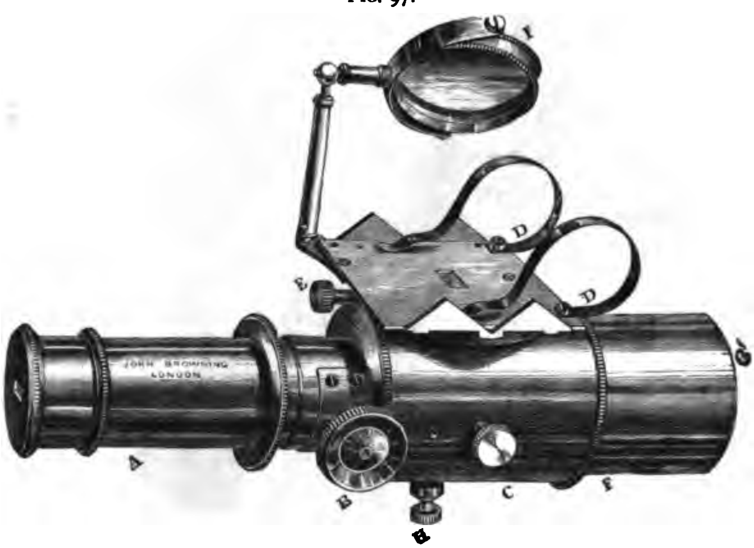
Absorption Bands of Human Blood.

inner tube can be made to slide, so as to bring the slit in the focus of the lens *l*, so that the rays from the slit, after passing through the lens, fall parallel on to the prisms.

DD is the stage on which the objects for comparison—liquids between plates of glass or in small tubes—are secured within notched edges, by means of metal springs by which the small glasses are held in such a position that the light, after its passage through the liquid, reaches a square

opening in the middle of the stage. Hence, as Fig. 98 shows, through a side opening *o* it enters the principal tube, and falls upon the reflecting prism P, which acts as a comparison prism. When not in use, the square opening in the stage DD is closed by a sliding plate by means of the screw E, so that the side-light may be excluded.

Fig. 97.



The Microspectroscope.

Fig. 99 shows the construction of the slit. The plate *n* is stationary, and the motion of the plate *m* by means of the screw H and an opposing spring serves to regulate the width of slit. The length of the slit is adjustable by means of the covering plate *p* under control of the screw *c*, acting against a spring. A portion of the slit is covered by the prism R, upon which the light from the object for comparison falls in the direction from *o*, and is reflected upon the system

of prisms *c*, together with the light coming through the unobstructed part of the slit (Fig. 99). Thus two spectra are received in juxtaposition, one produced by the light passing through the tube G, the other by the light transmitted through the liquid upon the stage DD.

FIG. 98

Section of the Microspectroscope.

The microspectroscope is brought into use by removing the tube A, with the prisms, and inserting the tube G into the eye-piece tube, so that the slit at the eye end shall be parallel to the inner slit. The object-glass is then screwed into the lower part of the microscope, the substance to be investigated laid upon the stage, and illuminated, according as it is transparent or opaque, with a mirror from below, or

by means of an achromatic condenser from above, and the focus adjusted. For this purpose it is requisite that the slit by means of the screw H should be opened wide. The tube A, with the compound prism, is then replaced, its position regulated with regard to the slit by the screw B, and the width of the slit adjusted until a well-defined spectrum is obtained. As each portion of the spectrum possesses a different degree of refrangibility, the prisms must be especially adjusted for each of the delicate absorption lines. It need scarcely be remarked that in these investigations only low powers are employed.

FIG. 99.

Adjustments for the Slit in the Microspectroscope.

If used in daylight, the microscope must be directed to a bright part of the sky (Fig. 97), and the mirror I serves to intensify the light upon the liquids on the stage DD.

For the determination of the position of the absorption lines, the upper cover of the tube A is removed and replaced by one (Fig. 100) provided with a lateral tube *aa*. In this tube the lens *e* can be adjusted by the screw *b*, while in front is a contrivance for carrying an opaque glass plate *d*, on which is photographed a fine transparent line or cross, and which may be moved backwards and forwards by the micrometer screw M—see Fig. 45—and the amount of motion measured. In front of the opening of the tube *a a* hangs the mirror S by which light is reflected on to the glass plate *d*. By turning the micrometer screw M the light transmitted through the glass plate is thrown into the tube A A, in the form of a bright line, and the lens *e* adjusted to such a position as to direct the image of this line upon the upper

surface of the range of prisms *c*, whence it is reflected in the direction of the principal tube, and reaches the eye at the same time as the spectrum. A bright line or cross is thus seen upon the spectrum, and, by the screw M, may be placed upon any absorption line, and the relative distances between any dark lines in the spectrum measured.

FIG. 100.

Micrometer for Measuring the Absorption Lines.

To facilitate the micrometric measures the instrument is provided with a scale, formed of a spectrum about 5 inches long, containing the chief Fraunhofer lines. The screw head M is divided into one hundred equal parts, and the readings of these divisions made to coincide with the divisions in the scale. When the position of a line is required in the spectrum under examination, all that is needed is to bring the line of light exactly over it by means of the screw M, and

read off the number. The numbers read off for the various lines need only be compared with the divisions of the scale of the normal spectrum, in order to determine the position of these lines in the spectrum for all similar investigations. Should a more complete representation of the absorption spectrum be required, it is only necessary to draw the lines according to the numbers read off on the micrometer screw-head upon a spectrum furnished with the scale of the normal spectrum.

Fig. 101.

Glass Globe for Absorbent Vapours.

53. Absorption of Light by Gases and Vapours.

As has been already said, colourless gases only weaken the intensity of the light they transmit, and exert no selective absorptive power upon any rays; and coloured solid and liquid bodies wholly absorb certain rays, and entirely transmit others, thus producing wide absorption bands extending sometimes over whole groups of colours in the continuous spectrum. *Coloured gases and vapours*, however, show only narrow dark bands which, like black lines, traverse not unfrequently every colour in the continuous spectrum.

For the exhibition of these absorption phenomena a glass globe (Fig. 101) is employed, smoothly polished inside, and capable of being closed at both ends by pieces of plate glass. The vapours for examination are introduced into the globe by a side opening; but if it is desirable that they should be formed during the investigation, the substances required can be placed in the vessel by removing the cover, and vaporized by a careful application of heat. The globe must

be placed immediately before the prism, or close in front of the slit of the spectroscope, and in such a position in the path of the rays that they may pass through the inside of the sphere perpendicularly to the glass plates covering it.

To exhibit the absorptive properties of nitrous acid gas on a large scale, the electric lamp or the Drummond light must be employed, and the continuous spectrum of white light thrown upon the screen in the manner described in § 18, Fig. 29. If the globe filled with the red vapour of nitrous acid (nitrogen tetroxide)* is placed in front of the prism, the spectrum will appear crossed by dark bands, while the violet end has disappeared. By heating the vapour these bands become stronger, and new bands successively appear, until all the coloured portions of the spectrum are absorbed, and not a ray of the electric light is able to penetrate the vapour. Brewster carried the process so far as to render the gas entirely opaque even to the sun's visible rays. The absorption spectrum of this gas is shown in Fig. 90.

If some pieces of iodine are placed in the globe and heated, a violet vapour is produced, through which the electric light may be sent. The phenomena which are then seen differ greatly from those before exhibited; by slightly widening the slit a large piece of the spectrum, from the beginning of the yellow to the blue, appears to be cut out, and if the slit is contracted so as to obtain a purer spectrum, this broad dark belt resolves itself into numerous fine dark lines, which are seen to cross the whole of the spectrum from the red to the beginning of the blue. If the absorption spectrum of the vapour of iodine in a test tube is examined by means of a spectroscope, the whole of the orange and yellow will be seen crossed by numerous fine

* The vapour is obtained in the simplest and most convenient manner by heating nitrate of lead, a process which may take place either in a separate vessel or with care in the glass globe itself.

black lines which increase so much in the green that they are scarcely separable, and appear to form a shaded band. With instruments of great dispersive power these dark bands are resolved into very fine lines, increasing in number and intensity towards the middle and darkest portions of the bands.*

Other coloured gases yield similar absorption spectra, particularly the vapours of bromine, hydrochloric acid, perchloride of manganese, also, according to Morren, of chlorine,† etc.; while there are other vapours, such as those of sulphur and selenium, which, although coloured, do not occasion any absorption bands in the spectrum.

Aqueous vapour also exercises an absorptive action upon light, and its absorption lines are very noticeable in the spectrum of solar light, and that of diffused daylight. We shall leave the consideration of the details of these phenomena till we come to the discussion of the solar spectrum.

54. Relation between the Emission and the Absorption of Light.

When it is remembered that solid bodies in a state of incandescence *emit* a much greater body of light than do gases in a similar condition, and that they are able to *absorb* a much greater quantity of the light falling on them,—in certain circumstances even the whole of it,—through the transfer of the ether vibrations to their ponderable atoms; when, further, it is remembered that just those substances that *give out heat* with the greatest facility, and in the fullest

* [The absorption spectrum of iodine vapour is a most beautiful one when examined with good dispersion; the bands composed of fine lines are rhythmical, as are also the lines themselves.]

† [Principally situated in the ultra-violet.]

quantity, are also the most capable of ***receiving heat*** from without or ***absorbing*** it, the thought is suggested that there must be an intimate connection, a certain reciprocity between the power of a body to emit light (***emission***) and to absorb it (***absorption***). That the temperature of the substance has an influence on this relation between its emissive and absorptive powers is proved by the phenomena of the gaseous spectra of the first, second, and third orders (§ 47), as well as by the variety of absorption spectra exhibited at different temperatures by the same substance. A century ago the eminent mathematician and physicist Euler, in his "*Theoria lucis et caloris*," enunciated the principle that every substance absorbs light of such a wave-length as coincides with the vibrations of its smallest particles. Foucault mentioned in his work on the spectrum of the electric light, published in 1849, that owing to the impurity of the carbon points, the intense yellow sodium line appeared, and was changed into a black line when sunlight was transmitted through the electric arc. In October 1841 it was remarked by Brewster that when nitre was burnt upon charcoal, bright, well-defined lines appeared corresponding with the dark lines A *a* and B* of the solar spectrum, which led him to suspect that there was an intimate connection between these phenomena, though he did not further prosecute his researches in this direction. In 1852 Professor Stokes, in considering the coincidence of the double bright line of sodium with the double dark line D of the solar spectrum, more clearly recognized the significance of the phenomenon, and offered the following explanation : The light given out by an incandescent vapour depends upon the vibrations of its molecules, in the same way as the tone of a note of a piano depends upon the vibrations of the string. If a note is sounded in a room

* [The Fraunhoferic lines so designated do not coincide with those obtained from the nitre.]

where there is a piano, it will be found that the string answering to that note will respond by giving out the same tone. The same thing occurs with regard to light; when light passes through a vapour, the molecules of which have power to vibrate in any certain relationship, these are stimulated by the rays of light passing amongst them to vibrate in concert with them, but only such rays can transfer their vibrations to the gas molecules as are vibrating in unison with them. But in proportion as the light transmits to the gas molecules its own vibrations, it loses energy itself, and becomes weakened or extinguished, but this can only occur in such rays as vibrate in coincidence with the gas molecules. It is evident that it depends entirely upon the nature of the vapour through which white light passes which portions of the light will be lost, or, in other words, which colour will be weakened or absorbed by the vapour. When, for instance, white light passes through vapour of sodium, the only rays* which will be weakened will be those corresponding to the two yellow lines of this vapour, and in contrast to the other rays they will appear dark.†

Ångström gave expression as early as the year 1853 to the general law that a gas when luminous *emits rays of the same refrangibility as those which it has power to absorb*, or, in other words, that *the rays which a substance absorbs are precisely those which it emits when made self-luminous.*

But all these facts remained isolated, and there was yet wanting the comprehensive grasp of a general physical law under which the individual phenomena could be arranged. It was reserved to Kirchhoff to discover this law, and to

* At this very time this subject was engaging the attention of Professor Balfour Stewart, who subsequently offered an explanation essentially agreeing with the foregoing.

† [This is only true when the sodium vapour is at a low temperature.]

establish triumphantly its truth, not only by mathematical proof, but also in many striking instances by experiment.

In the year 1860 he published his memoir on the relation between the emissive and absorptive powers of bodies for heat as well as for light, in which occurs the celebrated sentence: "*The relation between the power of emission and the power of absorption for rays of the same wave-length is constant for all bodies at the same temperature.*" This axiom announces one of the most important laws of nature, and, on account of its importance, will render the name of its illustrious discoverer immortal.

55. Reversal of the Spectra of Gases.

From Kirchhoff's law it follows that gases and vapours in transmitting light absorb or degrade in intensity precisely those rays (colours) which they themselves emit when rendered luminous, while they remain transparent to all other coloured rays. Luminous sodium vapour, for example, gives under ordinary circumstances a spectrum of a close pair of bright yellow lines; it emits therefore this yellow light only. If the white light of the sun, the electric arc, or the oxyhydrogen lamp is allowed to pass through the vapour of sodium, the vapour will abstract or extinguish from the white light just those yellow rays which it emitted when in a luminous state. While the greater part of these yellow rays are absorbed by the sodium vapour, all the other rays—the red, orange, green, blue, and violet—pass through nearly undiminished.

Kirchhoff's experiments admit of easy repetition by means of a direct-vision spectroscope, or even with a small pocket spectroscope. After a distinct spectrum has been formed from the white light of a lamp, a glass tube closed at either

end by glass, from which the oxygen of the air has been expelled by the introduction of hydrogen gas, and in which are laid some pieces of metallic sodium, is placed in front of the slit. The glass tube is heated by means of the spirit lamp or gas-flame, and part of the sodium is converted into vapour; a dark line soon makes its appearance in the bright yellow of the continuous spectrum of the oil lamp precisely in the place where the sodium vapour when rendered luminous by heat shows its yellow line. To prove this it is only necessary to replace the sodium tube by a spirit flame on the wick of which some common salt (chloride of sodium) has been rubbed, and to screen the light of the lamp: the luminous sodium vapour produces the yellow line precisely in the same place in which the yellow light was before absorbed from the continuous spectrum and the dark line formed.

Opticians furnish strong glass tubes half an inch in width, closed at both ends, and filled with hydrogen gas and a small quantity of sodium. On being slowly and gradually heated, the sodium becomes vaporized. If such a tube is held vertically close in front of the slit, and the white light of a petroleum lamp or gas-flame, or, what is preferable, the light from incandescent lime, is allowed to pass through the tube containing sodium vapour before entering the slit, a dark line is visible precisely in the place of the bright sodium line. By the use of a spectroscope of strong dispersive power the bright sodium line appears doubled; accordingly with such an instrument the dark absorption line of sodium vapour also appears double, and situated precisely in the same place as the two bright lines.

In the same way, by employing the vapours of lithium, potassium, strontium, and barium, Kirchhoff and Bunsen cut out of a continuous spectrum precisely the same bright colours which these vapours emit when luminous. Lumi-

nous lithium vapour (Fig. 83) gives a spectrum of one intense red line and a fainter orange one; lithium vapour absorbs these identical rays, the absorption of the orange ray being less marked than that of the red.

In this field of investigation, by means of a powerful induction machine and a battery of fifty elements, Cornu has succeeded in reversing the bright lines of a great number of metals.* His mode of proceeding was as follows. The positive pole consisted of a cylinder of carbon from 2½ to 3 inches in diameter, in which a hollow was formed for the reception of the metal to be examined. The negative pole was then brought so near that the electric arc was scarcely ¼-inch long. By means of a lens the image of this arc was thrown upon the slit of a spectroscope. If, for instance, a piece of magnesium was placed in the hollow of the carbon forming the positive pole, there would appear in the spectrum the triple line *b* with great sharpness and brilliancy. But if the upper carbon was made gradually to approach the lower one, the lines would be seen to widen and become less and less defined, till at last there would appear a fine black line upon the side of least refrangibility. By bringing the carbons still nearer together the second, and finally the third bright line would change into dark lines.

The reason why the bright lines did not become reversed at the same time is worthy of notice. It was remarked by Cornu that the lines that first changed were always those of least refrangibility, and that the changing of bright to dark lines proceeded as the temperature advanced. He gives the following table of the lines he has been able to reverse; the metals are arranged nearly according to the facility with which their lines become reversed, and are given with

* [During Lockyer's comparison of metallic lines with the solar spectrum he noted the reversal of many lines which up to that time had not been observed reversed.]

their colours and their wave-lengths in millionths of a millimetre:

Sodium	yellow lines . . .	589
Thallium	green line . . .	535
Lead	violet line . . .	406
Silver	green lines . . .	521
	violet lines . . .	424
Aluminium	violet lines between H_1 and H_2	396
		394
Magnesium	triple green line . .	518·30 the least refrangible.
	triple ultra-violet line near L . . .	383·78 the least refrangible.
Cadmium	green line . . .	509
	blue-green line . .	480
	blue line . . .	467·7
Zinc	green line . . .	481
	green line . . .	472
	blue line . . .	467·8
Copper	green line . . .	510

In iron, cobalt, bismuth, antimony, and gold Cornu was unable to obtain even the faintest indication of reversal, while in certain compounds of chlorine, such as sodium and lithium, the reversal was readily effected.

By means of Siemens' powerful dynamo-electric machine, Liveing and Dewar have since succeeded in reversing the lines of a great many other metals, among them the intense lines of the G-group of calcium, and several of the lines of silver.*

The important result of these investigations is therefore that the characteristic *bright* lines of sodium, lithium, and the other metals are changed into *dark* lines when the intense white light of incandescent solid or liquid bodies passes through the vapour of these metals. As therefore the bright

* [They have recently added many more to this list.]

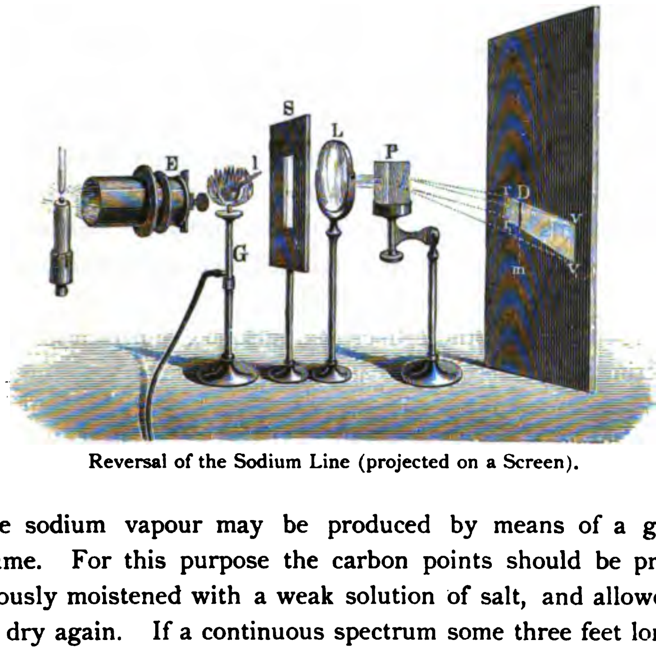
lines of the spectra of vapours are converted into dark lines, while the dark parts of the spectrum are changed into brilliant colours by the continuous spectrum of the white light, the entire gas spectrum seems to be reversed in respect of its illumination; for this reason the phenomenon was called by Kirchhoff "*the reversal of the spectrum.*"

It has been fully proved by Kirchhoff that the difference between the temperature of the incandescent solid or liquid body giving the continuous spectrum and that of the absorptive vapour through which its white light passes exercises a great influence upon the reversal of the spectrum. The whole phenomenon rests upon the relation existing between the emissive and absorptive powers of the vapour, which relation is determined by the difference in temperature. Reversal experiments, therefore, only succeed when there is a great difference of temperature between the incandescent solid body and the absorptive vapour, and they succeed with greater certainty the higher the temperature of the incandescent body, and the lower that of the reversing vapour. The light of the sun, the electric arc, the lime-light, or a glowing platinum wire, may be employed in place of the lamp. If, instead of the glass tube filled with hydrogen and sodium, etc., free sodium vapour is employed, such as can be obtained by heating metallic sodium in a flame, this flame must not be of a high temperature. The temperature of the Bunsen burner, or even of a spirit lamp, is too great to show the phenomenon when the luminous source is the oxyhydrogen light; the difficulty may be overcome by diluting the spirits of wine with as much water as it will bear, and adding to the flame a little common salt, when, with a suitable opening of the slit, the sodium line will appear black upon the continuous spectrum of the lime-light. If the electric arc light, with its far greater heat, is used to form the con-

tinuous spectrum, the reversal of the sodium and lithium lines may be produced by volatilizing these metals in the flame of the Bunsen burner.

To show the reversal of the sodium line effectively on a screen, the glass tube above mentioned containing hydrogen gas and sodium is not well suited, as the sodium vapour is not dense enough, and condenses on the sides of the glass; but if the electric light is used for the white light,

FIG. 102.



Reversal of the Sodium Line (projected on a Screen).

the sodium vapour may be produced by means of a gas flame. For this purpose the carbon points should be previously moistened with a weak solution of salt, and allowed to dry again. If a continuous spectrum some three feet long is formed by the electric lamp and prism in the usual way, the bright sodium line is seen passing through the yellow, the position of which may be noted by making a mark *m* beneath it. The small amount of sodium adhering to the carbon points soon evaporates in the heat of the electric light, and the yellow line is extinguished. The gas burner G

(Fig. 102) is now placed before the slit of the electric lamp E, so that the rays of the incandescent carbon issuing from it must pass through the flame G. Before adding the sodium to this gas flame, a perforated screen S is placed in front of the lens L, in order that the large screen on which the spectrum is formed shall be protected from the intense yellow light of the burning sodium. A piece of sodium the size of a pea is placed in a platinum spoon *l*, and brought into the gas flame; the sodium ignites, and forms a dense cloud of vapour in the path of the rays of the electric light. On the screen is seen a stripe D of intense blackness, precisely in the place marked *m* where the bright sodium line before appeared; the sodium vapour has, partially at least, absorbed from the white light of the incandescent carbon the yellow light of the same degree of refrangibility as the sodium vapour emitted. If the sodium is withdrawn from the gas flame, the black line immediately disappears from the screen; if it is re-introduced, the black line again appears precisely in the same place.

The reversal of these lines may also be shown as in the experiments of Cornu, p. 194. The rationale of the process is as follows: as the sodium becomes intensely heated, a part turns to vapour and emits its yellow light; immediately afterwards a great portion of the sodium is converted into *vapour*, and envelops the luminous portion surrounding the sodium in a dense cloud of non-luminous sodium vapour. The yellow light of the small luminous portion of the sodium vapour must pass through this large cloud of sodium vapour of a lower temperature, and is absorbed by it before reaching the slit of the spectrum apparatus.

Weinhold has suggested a simple and most instructive arrangement for exhibiting the reversal of the sodium lines, in which the portions on either side of the sodium line of a *continuous* spectrum are as much increased in brilliancy as

the sodium line is intensified by the luminous power of the sodium vapour.

The light from the bright flame of an ordinary petroleum lamp is received through the narrow slit of a collimator tube, from which the lens has been removed, by a *powerfully dispersive* prism of bisulphide of carbon, or better still on to a system of two such prisms. When the image has been carefully adjusted a spirit flame *intensely* coloured by salt is introduced between the prism and the eye, so as nearly to cover the whole spectrum. The *dark* absorptive lines of sodium immediately appear clearly and sharply in the orange, while if the spirit flame is removed and placed between the petroleum lamp and the slit, the lines are changed to brilliant ones. In preparing the spirit flame it is desirable to weaken the spirit with water and then to saturate this solution with salt, and besides this to rub salt from time to time into the wick, since the more intense the yellow of the flame, the blacker will the sodium lines appear. Care must be taken not to fix the eye upon the spirit flame, but to look through it on to the spectrum beyond, and thus accommodate the eye to the setting of the slit.

We can now foresee what appearance will be presented in the spectroscope if the light of an incandescent solid or liquid body, before entering the slit of the instrument, pass through a less highly heated atmosphere of any kind of vapour, such as that of sodium, lithium, iron, etc. The incandescent body would have produced a continuous spectrum if its light had sustained no selective absorption on the way. In the vaporous atmosphere through which its rays must pass, each vapour absorbs just those rays which it would have emitted if luminous, extinguishing these particular colours, and substituting for them dark lines in those places of the continuous spectrum where it would have produced bright lines. The spectroscope shows therefore

a continuous spectrum extending through the whole range of colours from red to violet, but intersected by dark lines, the sodium line, the lithium lines, the numerous iron lines, etc., appearing on the continuous spectrum as so many *dark* lines.

Spectra of this kind are evidently *absorption spectra;* they are also called *reversed spectra.* If a *complete coincidence* can be established in such a spectrum by means of either a comparison prism (Fig. 49), or a scale (Fig. 43), between the characteristic *bright* lines of the gas spectrum of a certain substance with the same number of *dark* lines, it may be concluded that the same substance is contained in a state of vapour in the absorptive atmosphere which has produced the dark lines. The influence which this result of Kirchhoff's discovery has on the investigation of the physical constitution of the heavenly bodies is shown by the fact that exactly as the various terrestrial substances are recognized by their bright gaseous spectra, so do the reversed gaseous spectra afford the key to the recognition of the matter of which the heavenly bodies are composed.

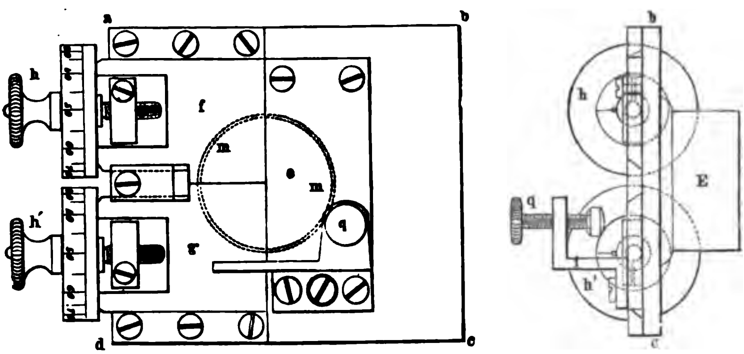
A discussion on the relative intensities of the dark and bright lines will be found in Appendix K.

56. Spectrum-Photometry. Vierordt's Apparatus.

The characteristic features of an absorption spectrum are not restricted to the number and position of the dark lines, but include also the degrees of illumination in the various parts of the spectrum, and to determine this by some better means than by estimation is often of great importance. A photometric arrangement for this purpose, applicable to any large spectroscope, has been devised by Professor Vierordt of Tübingen. It consists in covering one-half of the slit with a semi-transparent medium, the amount of light

obstructed having been previously ascertained. From the slit thus divided two spectra in immediate contact are formed, and therefore easy of comparison, one being the spectrum lowered throughout in tint, the other the pure spectrum from the source of light common to both. All the spectrum not under observation is shut off by two slides in the eye-piece of the telescope, occupying the position of the cross-wires. The problem requiring solution is to reduce the light of the pure spectrum to that of the degraded one, or in other words to lessen the brilliancy of the former by a known quantity.

FIG. 103.



Section of the Spectrum Photometer.

For this purpose the slit must be so contrived that the width of opening of each half may be separately controlled. The end of the tube E (Fig. 103) through which the light is received is covered with the square plate *a b c d*, in the centre of which is the circular opening *m m* of the same diameter as the tube. Upon this lie the three plates *e*, *f*, and *g*, the inner edges of which coincide with those of the slit. The plate *e* forming one side of the slit is stationary, while the plates *f* and *g* forming the other side are provided with separate motion, each being mounted on a micrometer screw terminating in a divided screw-head (*h h′*) carrying

one hundred divisions. By the aid of these the width of slit may be ascertained by the observer without quitting the telescope. The adjustable plates are both on the same side in order that the corresponding portions of both spectra may be in exact superposition; while the spectra are being compared, the width of the slit is readily controlled by the screw-heads.

The horizontal plate *i* projecting from under the lower half of the slit serves as a stage for the reception of small smoked glasses, the height of which must not exceed that of the half-slit, so that their obscuring effect shall not extend beyond. The screw *q* may be dispensed with, but is of service in holding the smoked glass in a perpendicular position when the slit is placed vertically.

In the upper part of the field of the telescope the pure spectrum of the source of light appears, corresponding with the lower half of the slit, and in the lower part the spectrum, after passing through the light-absorbing medium, is seen. If the difference in brilliancy between the two spectra is but slight, a moderate contraction of the lower slit suffices to reduce both portions of the spectrum to uniform brightness. If the difference is considerable, they must be equalized by placing in front of the slit one or more shaded glasses of ascertained density, the final adjustment being made by altering the width of slit. To prevent "interference" lines arising from the immediate contact of the smoked glasses, they are separated by strips of paper.

The amount of light remaining, after its passage through the absorptive medium, is therefore to be estimated by the width a of the slit, and the amount of light β known to pass through the smoked glass. Before commencing observation, both slits should have equal widths, corresponding to one revolution of the screw. The width of the half slit, barred by the transparent medium, remains unaltered, while the

other half slit is contracted till the screw-head reads exactly the value of α. The value of β, namely the amount of light transmitted by the smoked glass, should be accurately determined beforehand for *each portion of* the spectrum.

The necessity for this lies in the fact that the amount of light observed through the dark glass is not the same for all colours. It is desirable to have two varieties of dark glass—slightly shaded and very dense. For the solar spectrum the latter are indispensable; for fainter spectra a combination of delicately shaded glasses is sufficient. The absorbent power of a faintly shaded glass may readily be determined by placing it across one-half of the slit, and reducing the bright spectrum of the other half to the same degree of intensity by contracting the slit. The estimation may be verified by enlarging the slit of the shaded spectrum till it equals the neighbouring one in brightness. The power of a dense glass can be measured by discovering what combinations of lighter shades make an equivalent. Professor Vierordt has applied his instrument to determining the relative brightness of the various parts of the solar spectrum. If the total light is taken at 1,000,000, the mean brightness of the principal parts is as follows:—

A to *a*	72
a ,, B	1,592
B ,, C	4,114
C ,, D	288,957
D ,, E	478,544
E ,, F	186,143
F ,, G	36,190
G ,, H	4,383

The applications of Vierordt's apparatus are manifold; it is, however, peculiarly adapted to the investigation of the intensity of colour in coloured solutions. These, as they increase in strength, always augment in absorptive power with light of certain wave-lengths. The coefficients of

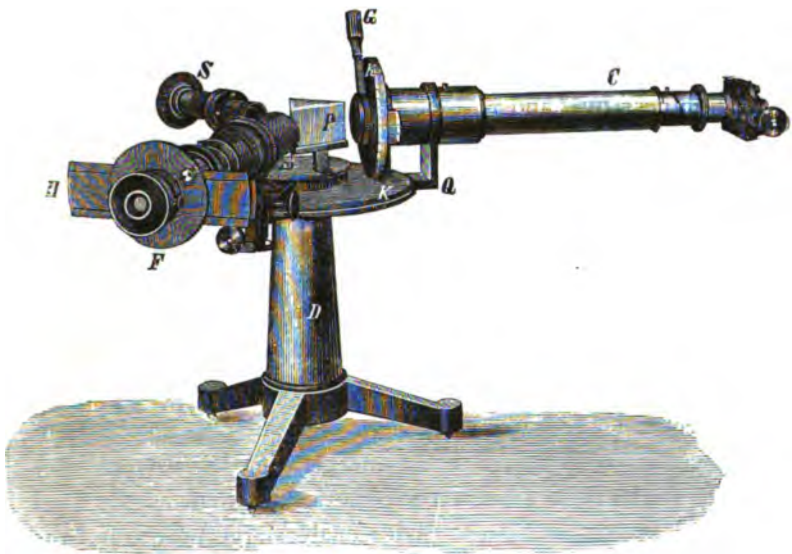
extinction of light which has passed through the unit stratum of liquid increase in proportion to the strength of the solution; their relationship, termed by Vierordt their absorptive relationship, is therefore constant for every absorptive medium in any part of the spectrum. When, therefore, the relationship between an absorptive substance and light of a given wave-length has once been found, it is possible to ascertain the strength of a solution of unknown strength by measuring the amount of light of a certain colour lost in passing through the liquid. If a liquid is composed of two coloured substances the absorptive relationships of which are known for two portions of the spectrum, the quantity of each may be determined if at both places in the spectrum the loss of light is measured. In organic extracts, where colour is present, it may be decided by spectrum analysis whether the colouring matter is composed of one or more substances. If the former, the coefficient of absorption must maintain a constant relationship in any two or more parts of the spectrum, whatever the strength of the solution may be.

57. Glan's Spectrum Photometer with Vogel's Improvements.

The great disadvantage of Vierordt's apparatus is the widening of the slit. The increase of light thus gained entails the inclusion of the adjacent rays of the spectrum. In Glan's instrument this has been avoided. A sketch of it will be found in Fig. 104. F is the telescope, S the micrometer tube, C the collimator, and P the prism. The telescope is mounted so as to revolve round the central vertical axis of the instrument, and the micrometer tube also revolves upon a perpendicular axis, resting upon a stand within the circumference of the plate R, which is furnished

with divisions for the reading of angular distances. The slit can be regulated by a micrometer screw, and is divided into two halves by a metal plate about $\frac{1}{10}$ inch in breadth. In the tube C, behind the collimator lens, is a double refracting prism, which forms two images of each half slit, an ordinary and an extraordinary one, and these by their close juxtaposition greatly facilitate the comparison of spectra.

FIG. 104.



Glan's Spectrum Photometer.

Behind the Rochon prism is a Nicol prism, mounted upon an axis so as to be turned by the handle G, and the angular deviation is read off in minutes upon the circle K. If the Nicol prism is so turned that its principal surface coincides with that of the double refracting prism, the extraordinary image disappears; if turned 90° further, the ordinary image also disappears. Between these two positions the two images alternate in brightness, and there is an

angular deviation for the Nicol prism where both spectra at one particular part are identical in brilliance. If the brightness of two spectra is to be compared, a comparison prism is placed in front of one of the half slits, so that the rays from one source of light are reflected on to the slit, while the rays from the other enter it direct. The brightness of the two is rendered identical by turning the Nicol prism, and the angular distance it has travelled from its first position, when it was coincident with the double refracting prism, is the measure of the disparity in brightness between the two spectra. If this angle is designated by a, and the original brightness by t and τ_1, then the turning of the Nicol prism is to the equal brightness of both images $\tau_1 = t\, tan^2\, a$.

When the Nicol prism stands at zero, the ordinary image has wholly vanished; if it is slightly rotated, both images appear, and they may easily be brought to uniform brightness. The part of the spectrum under examination is screened off by the slide H, which consists of a flat plate with a round opening placed horizontally across the eye-piece. This plate is grooved at its edges, from which two smaller flat plates project. These latter can hold it in position at any moment by screws travelling in a slit and pressing against H. The ends of the plate are curved to the same extent as the lines of the spectrum. These plates enable large portions of the spectrum to be screened off at will.

An improvement has been added to this instrument by Professor Vogel which renders it available for stellar spectroscopy. The details are given in the sectional drawing Fig. 105. P is a simple prism, F the telescope provided with a sliding shutter H for the eye-piece. In the collimator tube C is an arrangement of prisms for polarization similar to that in Glan's instrument. R is the double refracting prism, N the Nicol prism mounted on an axis and controlled by the handle g, the amount of angular motion being

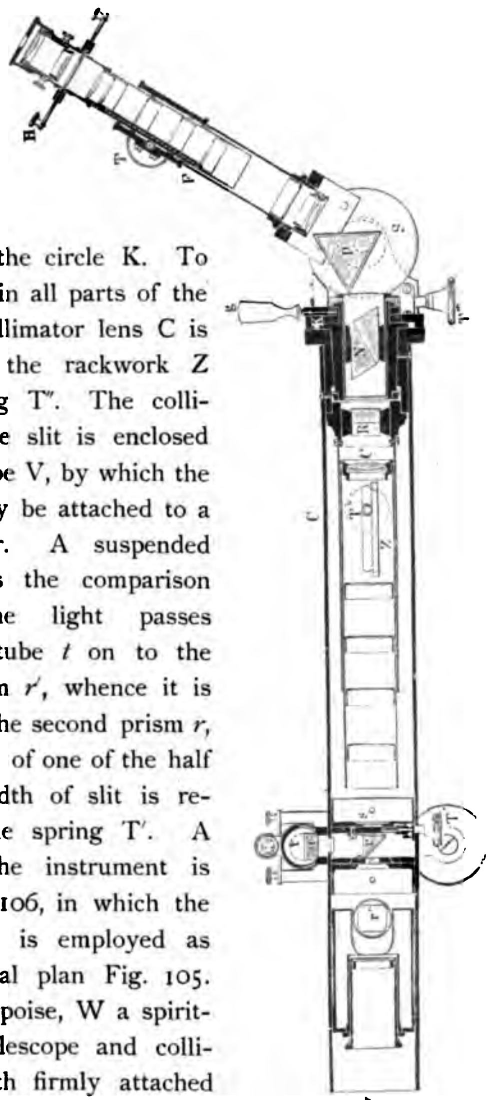
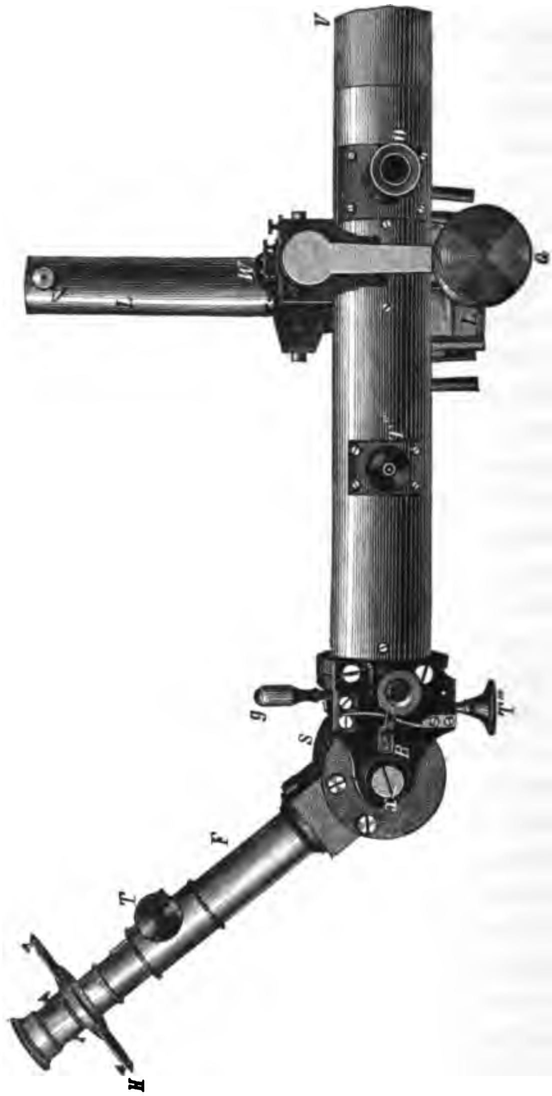


FIG. 105.—Vogel's Improved Spectrum Photometer, Section.

registered on the circle K. To secure contact in all parts of the spectra the collimator lens C is adjustable by the rackwork Z and the spring T''. The collimator with the slit is enclosed in the wide tube V, by which the instrument may be attached to a large refractor. A suspended lamp produces the comparison spectrum: the light passes through the tube *t* on to the reflecting prism *r'*, whence it is thrown on to the second prism *r*, placed in front of one of the half slits. The width of slit is regulated by the spring T'. A drawing of the instrument is given in Fig. 106, in which the same lettering is employed as in the sectional plan Fig. 105. G is a counterpoise, W a spirit-level. The telescope and collimator are both firmly attached to the solid plate B, which turns upon the axis *x* by means of the spring T''', working in the toothed wheel S. The amount of motion can be read off

Fig. 106.



Vogel's Improved Spectrum Photometer.

upon the divided circle attached to S. Beyond the slit there is another eye-piece *o* with the reflecting prism x''' (Fig. 106). This eye-piece acts as the finder of a telescope, and when the object—a star, for instance—is in the field of view the eye-piece can be withdrawn and the image allowed to fall upon the free half of the slit.

58. The Infra-Red Spectrum.

We have hitherto been occupied solely with the spectrum which is visible when white solar light passes through an ordinary glass prism or through a system of such prisms. The limits of such a visible spectrum are to be found near the lines A and H; the ether vibrations comprised within these limits can be perceived as light only by the eye. But the band of colour visible to the eye bounded by these limits forms but a part of the whole spectrum, which extends on both sides far beyond the red and beyond the violet. For the moment we shall confine our attention to that part beyond the red.

The discoverer of the infra-red part of the spectrum was the celebrated astronomer Sir William Herschel. He was led to its discovery in the year 1800, while searching for the colour best adapted for the construction of dark glasses for observations on the sun. While testing the coloured rays by directing them in succession through a small aperture in a piece of cardboard upon the blackened bulb of a thermometer, he found that all colours had not the same heating power. In violet light the thermometer rose 2° Fahr., in green light 3¼°, in red upon an average 7°, and when the bulb was placed about half an inch beyond the extreme red rays the thermometer rose 8¾°. At twice that distance the effect was not so marked, but even at a further distance it was still considerable. In 1819 Seebeck observed that

the position of maximum heat in the spectrum varied according to the nature of the prism employed, and that under certain circumstances it might even occur among the visible red rays. This was shown by Melloni to depend on the varying absorptive power of the prisms for the infra-red or heat* rays. He found that of all substances rock-salt was the most transparent to heat rays, and that by the use of a prism of this material the maximum heat occurred at a distance from the extreme end of the visible red, nearly as great as the red is from the blue in the visible spectrum.

So far then the existence of a dark spectrum below the red was known, but as to any other character besides its heating effect nothing was known.

[In 1840, however, Sir J. Herschel discovered that there were breaks in the infra-red of the solar spectrum, and that therefore, like the visible part, it was not continuous. His method of observation was novel. He allowed an image of the sun after passing through a prism to fall on a screen formed of bank post-paper, the front surface of which he blackened with lamp-black. This paper he moistened from the back surface with alcohol, a liquid which is easily, but not too easily, volatilized by heat. When the dark rays fell on the blackened surface of the paper screen the absorbed radiation did work on it by heating the lamp-black, which in its turn caused the alcohol to volatilize more rapidly at those parts than where unacted upon. Now if this portion of the spectrum were continuous, after sufficient time had elapsed to cause the differential evaporation of the alcohol there

* [The term "heat rays" is a misnomer, though we leave it in the text. No rays are heat rays, but these dark rays when they fall on proper absorptive material produce a rise of temperature in it. The visible and ultra-violet rays, but in a less degree, do the same. Rays are "energy carriers," and this energy may be expended in chemical action, in mechanical work, or in heat.]

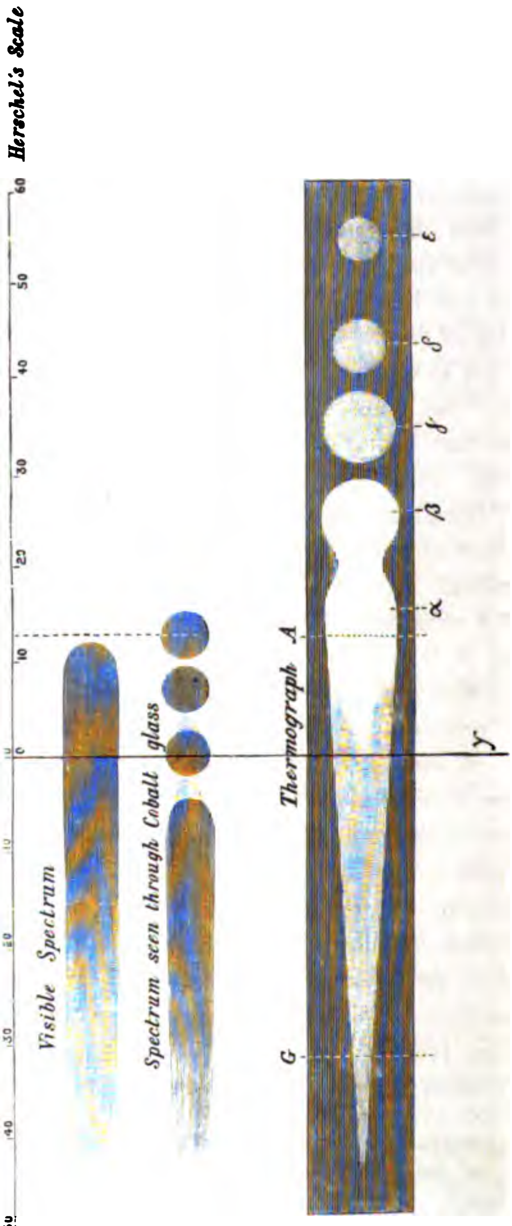
would have been a continuous strip of more or less dry paper where the spectrum had fallen. As a matter of fact, the band was broken up by several transparent or undried patches, and presented an appearance as in Fig. 107, showing that there were breaks in its continuity. The line marked *y* was the fiducial one used by Sir J. Herschel, and corresponded with the centre of one of the bright discs seen when the solar spectrum was viewed through cobalt glass. As the A-line can be seen through the last red disc, we have a good idea of the position of the spectrum. Regarding the furthest spot ϵ, till recently there was much doubt as to its existence. Sir John Herschel himself was not perfectly convinced that it was a reality, from the fact that it lay beyond the theoretical limit of the prismatic spectrum. Recently, however, Langley, and subsequently Abney and Festing, have shown that the real limit lies some way beyond the theoretical limit, which was calculated from Cauchy's formula for refraction. This spot ϵ, together with the others marked α, β, γ, and δ, are situated in the positions which more refined methods have shown they ought to occupy.]

Under ordinary circumstances the dark line A is not readily seen, but can be rendered much more conspicuous by the use of blue glass,* which by absorbing the brighter rays towards the orange emancipates the eye from their dazzling effect.

Matthiessen discovered in 1844 that in the infra-red there existed a dark band with a strong line in the centre as far beyond A as the distance from A to *a*, and this was to some extent confirmed by Brewster's observations in 1860. In the interim (1847) it had been noticed by Fizeau and Foucault, when using a highly sensitive thermometer, that

* [A combination of blue and red glass is better, and still better a solution of iodine in bisulphide of carbon combined with an orange glass.]

FIG. 107.



Thermogram of the Spectrum after Herschel.

there were some places in the invisible spectrum beyond A in which there was a diminished heating action. They were therefore to be regarded as absorption bands, but their exact position could not be determined by this method of observation. The phosphorescent action of a part of the infra-red spectrum was discovered by Edmond Becquerel. He noticed that if a sheet of paper painted over with sulphide of strontium after exposure to daylight is brought into a dark room, and then receives the image of a very pure and brilliant solar spectrum, the phosphorescence after a few moments will be destroyed from F to beyond A, and in the locality of the absorption bands beyond A a faint phosphorescence would be seen. Becquerel was thus able to trace the infra-red to a distance beyond A equal to that between A and D. By means of a carbon-disulphide prism and a crown-glass lens Becquerel discovered in this region, besides the double band A_1 and A_2, a group of four bands designated by him A', A'_1, A'_2, A'_3, and finally the broad band observed by Fizeau and Foucault, known as A'''. Further away still there appeared to be two other bands, but of these confirmation was needed.

Becquerel has given the wave-lengths and indices of refraction for these bands as follows :—

		Index of Refraction.	Wave-length.
A		1·6051	767·5
A′		1·5992	840
A‴	innermost edge	1·5877	1220
	middle	——	1265?
	outermost edge	——	1310

[In 1868 Desains published the results of some remarkable researches in this same region, using a thermopile for the purpose. He showed that the state of the atmosphere altered the place of maximum of heating effect, it being of a lower wave-length as the air was more or less dry.]

Lamanski's observations are of a later date. By investigating the solar spectrum with prisms of rock-salt, flint-glass, and carbon-disulphide, he found that the gaps in the heat rays were nearly constant in position; but it was noticed that in August and September the heat gaps, when using rock-salt prisms, increased in breadth with an increase of moisture in the air, which seemed to indicate a great absorption of the infra-red rays by our atmosphere. The heat spectrum of the lime-light shows a gradual increase, and subsequent decrease from the red outwards, without any gap, and the maximum is considerably further removed from the visible rays than in the solar spectrum. From experiments conducted by Müller with crown-glass and rock-salt prisms, in which the rays were directed on to a very sensitive thermo-electric pile, the action of the two prisms appeared almost the same within the limits of the visible spectrum, but in the infra-red the crown glass proved far more absorptive of the heat rays than the rock-salt prism. With the latter prism the extreme limit of the heat rays corresponded to a wave-length of 4,800 millionth of a millimetre.*

Fig. 108 gives a graphic representation of the heat rays in their varying intensity for different portions of the prismatic spectrum. Beneath are shown the principal Fraunhofer lines included between A and H, the portion constituting the visible spectrum. The portion from A to P represents the heat spectrum, while that from H to L is the ultra-violet, to which we shall again refer. The curved lines indicate the varying degrees of heat in the different parts of the spectrum. The curve A M H gives this line for the visible rays, the curve B D N represents the heat rays, the curve I K L the chemical rays, while the shaded

* [This was Müller's calculation, which we now know to be erroneous.

Fig. 108.

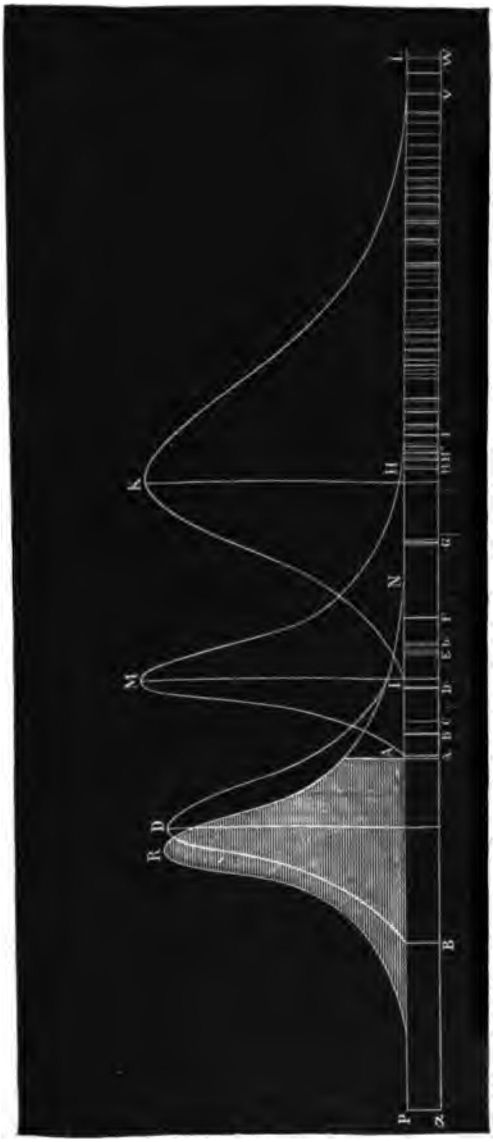


Diagram of the Various Intensities of Light, Heat, and Chemical Action throughout the Spectrum.

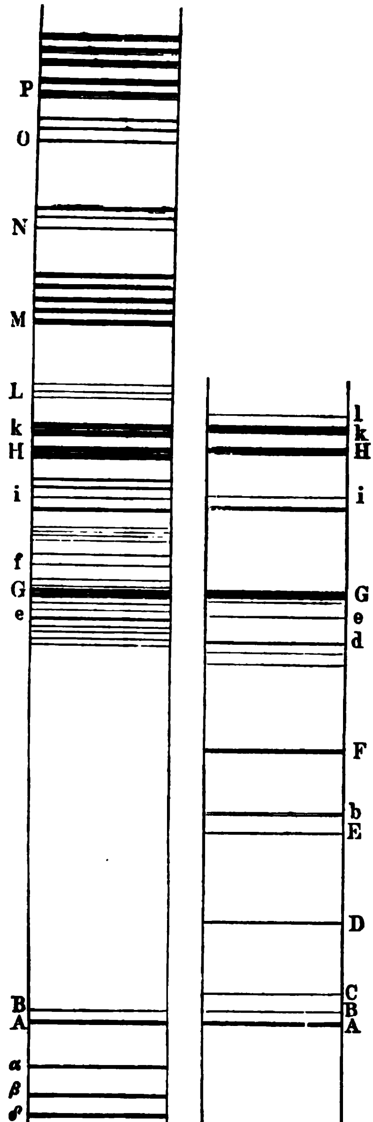


FIG. 109.* Draper's Tithonographic Spectrum.

outline P R N refers to the heat rays of the electric light (arc) as given by Tyndall.

It will be noticed that the maximum intensity of light occurs at M, in the yellow of the spectrum, while the maximum intensity of heat is at D, therefore in the infra-red, beyond A.

In 1843 J. W. Draper succeeded in obtaining a daguerreotype of nearly the complete spectrum. In Fig. 109 this spectrum is represented, called by Draper the *tithonographic* spectrum; below, for the sake of comparison, is added the visible spectrum with the Fraunhofer lines. It will be noticed that the daguerreotype includes not merely the infra-red, but also the ultra-violet part of the solar spectrum, and that the Fraunhofer lines are missing between A and *d*.

* [Fig. ~~109~~ 108 may be taken as fairly accurate for the curves R and M, but the curve with the vertex at K is misleading, as the chemical

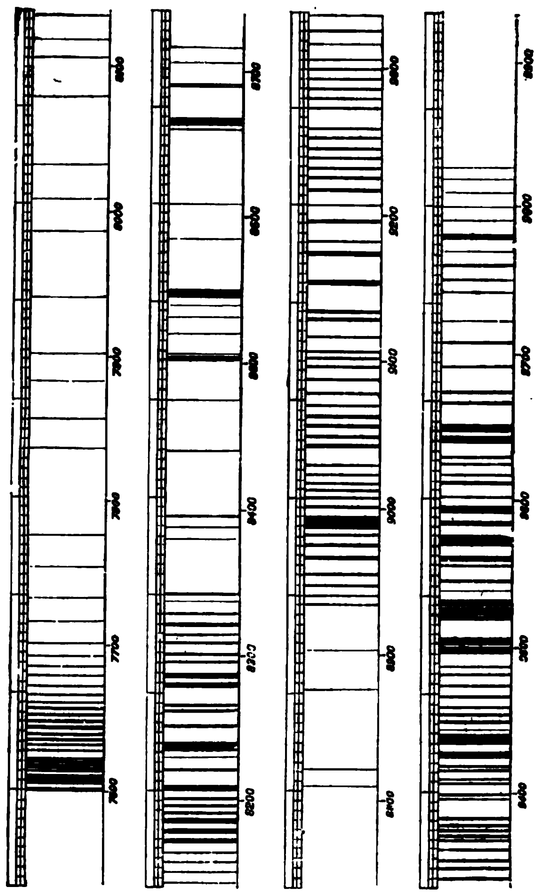
In Fig. 109 three lines stand out with marked prominence in the *infra-red* (invisible spectrum) designated by α, β, γ. These lines are not always seen so clearly on account of the feeble chemical action in this region. In the violet the most prominent were G, H, and *k*, and beyond the violet, outside the boundary of the visible spectrum, four groups were very distinctly seen. The first line of each group was designated by Draper in continuation of Fraunhofer's lettering M, N, O, P. L consists of two lines, M is a group of five, N and O of three each, and P of five lines. Beside these groups the whole region is traversed with fine lines too numerous to count, but Draper estimated that at least six hundred lay between H and P.

[The method Draper adopted to secure this spectrum was a novel one, depending on the fact that the red and infra-red rays have the power of apparently undoing the work of white light. Abney has traced this action to an oxidizing action produced by these rays on silver compounds, which have been acted upon by white light. The oxidation of the iodide of silver, which has been acted upon by light, produces a compound which is not developable by mercury vapour, nor indeed by any other developer. The plate on which the spectrum was taken was first given a slight exposure to white light, or else, whilst being exposed to the spectrum, white light of feeble intensity was allowed to play upon it. The blue and all the more refrangible rays acted in the ordinary manner, whilst the red rays apparently undid the work done by the white light, though in reality it made it undevelopable. Thus the spectrum presented a singular appearance. In the top diagram of Fig. 109, the right-hand side of the spectrum, viz., the blue and violet, from G to P presented the appearance of dark Fraunhofer

effect of the spectrum is variable according to the substance on which it falls.]

lines on a lighter background, whilst from B in the red to δ in the infra-red, the Fraunhofer lines appeared as white upon a dark background. In the blank space in the yellow and green between B and G the spectrum had no action.

FIG. 110.



Map of Infra-red taken with a Grating by Abney.

This method is one easily repeated, but is unsatisfactory for many reasons. In 1875 Capt. Abney first brought before the Royal Astronomical Society the first proofs that this region was capable of being photographed in a direct manner.

He originally secured his photographs by the addition of a resin to an ordinary photographic plate; but he abandoned this plan for a better one, the results of which he published in 1880 in a paper to the Royal Society. This paper was accompanied by a map obtained from photographs taken with the diffraction grating, the sensitive salt being formed of a peculiar and novel kind of silver bromide. Ordinary bromide of silver is orange by transmitted light, absorbing the blue and violet rays, and consequently is only acted on by these rays. The bromide Abney employed was green by transmitted light, absorbing the red and dark ray below, and consequently was acted upon by these rays. In the map he showed some 190 lines* below A, extending to a wave-length of 12,000, or a length more than equal to the spectrum ordinarily visible. Fig. 110 shows this map.

FIG. 111.—Photographed Spectrum. Infra-red.

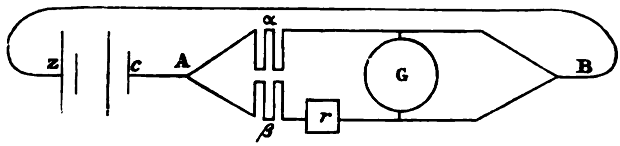
In the same paper he showed that with a prism, rays as low as 22,000 could be photographed, and the prismatic spectrum presented an appearance very analogous to that given in Fig. 111.

In 1882 Professor Langley published the results of a remarkable research in this region of the spectrum, using an instrument of his own invention for his investigations. This instrument, which he named the Bolometer, consisted essentially of two equal coils of very narrow and thin iron. Fig. 112 will give an idea of the principles of the instrument. C

* [In a revised map about to be published he shows treble that number.]

is one pole of a battery, and Z the other. These poles are connected as shown: α and β are two coils of fine iron, and at A the current divides, one part traversing α and the other β. G is a galvanometer interposed as shown. When the two coils α and β offer exactly the same resistance to the current

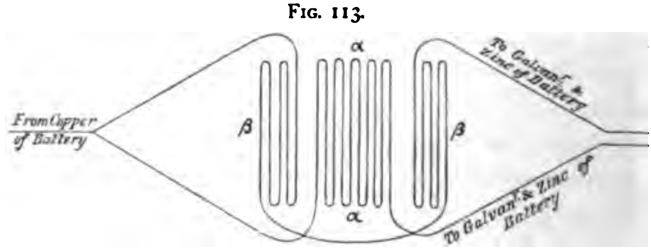
FIG. 112.



The Bolometer.

from C, none of it will pass through the galvanometer, whilst if the resistance be unequal, part of the current will pass through it. Now iron, when heated, offers an increased resistance to the passage of the current. If, therefore, the

FIG. 113.

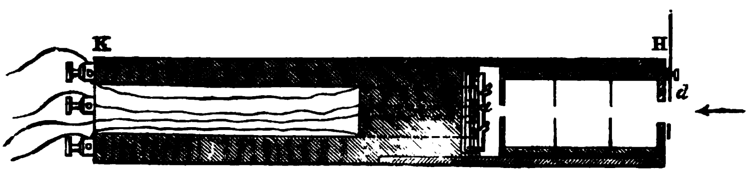


Arrangement of Strips in Bolometer.

resistances of α and β when at the same temperature be made equal, and then a small portion of one of them be heated, a current will flow through G. Langley used this principle to measure the heating effect of the spectrum. Fig. 113 gives an idea of the arrangement of the iron strips. They were $\frac{1}{50}$ of an inch wide, and so thin that it would take 12,000 strips laid one on the other to make up an inch. Fig. 114 shows the complete instrument. The part of the

spectrum he examined falls on the slit *d*, and reaches the coil *a*. The heating effect on the coil allows the current to pass through the galvanometer and causes a deflection of the needle, the amount of which measures the heating effect. By moving the slit through the spectrum he was able to compare the heating effects at every part; and not only so, but owing to the fineness of the iron strips, he was able to indicate the regions where there was the same lack of radiation as there is of necessity in the Fraunhofer lines. By this ingenious plan he was able to map the whole of the infra-red region to an enormous distance, the lowest wave-length being about 28,000, or nearly two octaves below the visible spectrum. A

FIG. 114.



Bolometer in Action.

delicate thermopile will measure the $\frac{1}{10,000}$ of a degree above the temperature of its surroundings. Langley estimates the bolometer will measure $\frac{1}{100,000}$ of a degree, and that the heat necessary to cause a deflection in the galvanometer is so small that it would take 1,000 years for it to melt a kilogramme (2 lbs.) of ice.

Fig. 115 shows the prismatic spectrum obtained by this plan. The vertical heights of the curve measure the relative heating effects of the different portions, and the great gaps first discovered by Sir John Herschel are plainly marked, amongst which is the disputed break (Fig. 107) between δ and ϵ, ϵ being shown as a mountain of heating effect. Langley used both the prism and the diffraction grating in his researches, the latter being employed as far as any

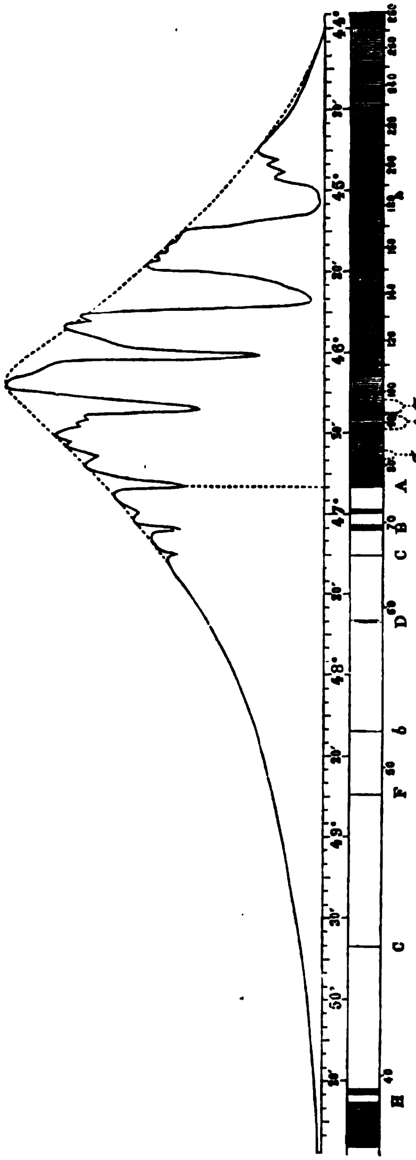


FIG. 115.—Langley's Prismatic (Bolometric) Solar Spectrum.

results could be obtained (we believe to somewhere near 24,000). Thus there cannot be much doubt as to the accuracy of the wave-lengths indicated by him, at all events to that point. It may be noted that the theoretical limit of the *prismatic* spectrum below A is nearly the same distance as E is above it; whilst Langley has shown radiation to exist as far below A as G is above it. Müller, who used the thermopile at a much earlier date, found nearly the same limit as Langley. Fig. 116 shows Langley's normal spectrum.

Allusion has already been made to Edmond Becquerel's discovery of the action of the infra-red on phos-

phorescent sulphides. Quite recently his son, Henri Becquerel, has continued these experiments, and produced some very notable results with this method.

Blende (hexagonal), reduced to fine powder, was dusted over a gummed card, and gives a green phosphorescence, which is rapidly extinguished by the infra-red rays. Solar rays were reflected by the mirror of a heliostat, and passed through two parallel slits. The rays which passed through the first fine slit fell on a prism of 60° of bisulphide of carbon, then on a lens which formed an image on the blende screen. Through the second slit, which was wide, rays of light fell on a flint prism, and then on the screen without falling on the lens.

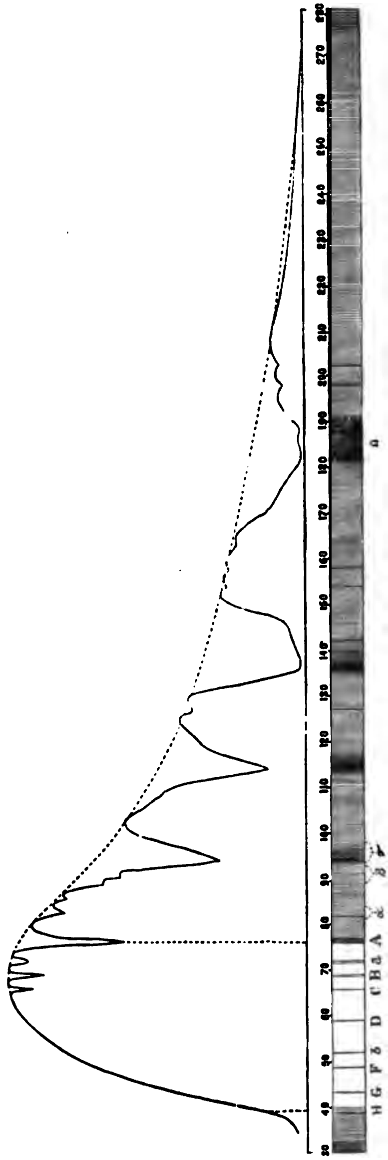


Fig. 116.—Langley's Normal (Bolometric) Solar Spectrum.

Thus the infra-red of the first spectrum could be superposed over the violet of the second, which latter excited the plate, whilst the former extinguished it.

Henri Becquerel states that the blende allowed him to go further in the infra-red than other substances did, though he tried the following:—

Substance.	*Phosphorescence.*	
Hexagonal blende	green.	
Barium sulphide	yellow orange.	
,,	green.	
Strontium sulphide	yellow.	
,,	green.	
Calcium sulphide	yellow.	
,,	green.	
,,	bluish green.	
,,	greenish blue	very luminous.
,,	deep blue	very luminous.

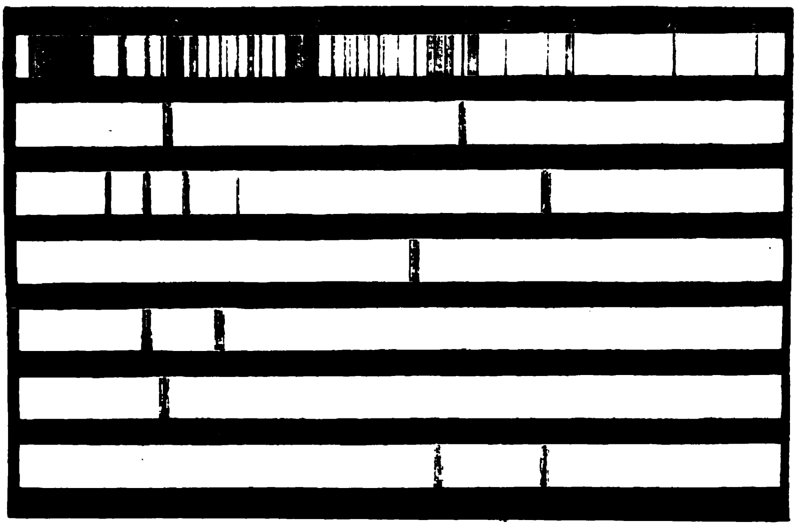
These bodies are all beautifully phosphorescent substances. From the results of these experiments he has drawn the solar spectrum, and determined the position of some of the bright lines due to metals. The annexed cut (Fig. 117) gives the drawing made by Becquerel. He has deduced from the above the normal spectrum from which the following wave-lengths are taken :—

The edge of A″	12,200
Magnesium line between A‴ and A″	11,310
Line to left of A″	10,970
A″	10,820
Centre of A′	9,360
Another magnesium line	8,750
Y	8,190
Z	7,940

These lines are not quite in the position determined by the grating and photography, but are as near as can be expected from the method employed. The greatest wave-length shown is 14,800, a wave-length which has nearly to be

doubled before the known limit of the solar spectrum is reached, as shown by Langley and confirmed by Abney and Festing. The region explored by M. Becquerel is that which it is easy to obtain by means of photography, and it seems as if below that point phosphorescence is incapable of giving any knowledge. The fact, however, that phosphorescence can give so much, is interesting; but great sharpness of detail can never be hoped for, since one particle

FIG. 117.



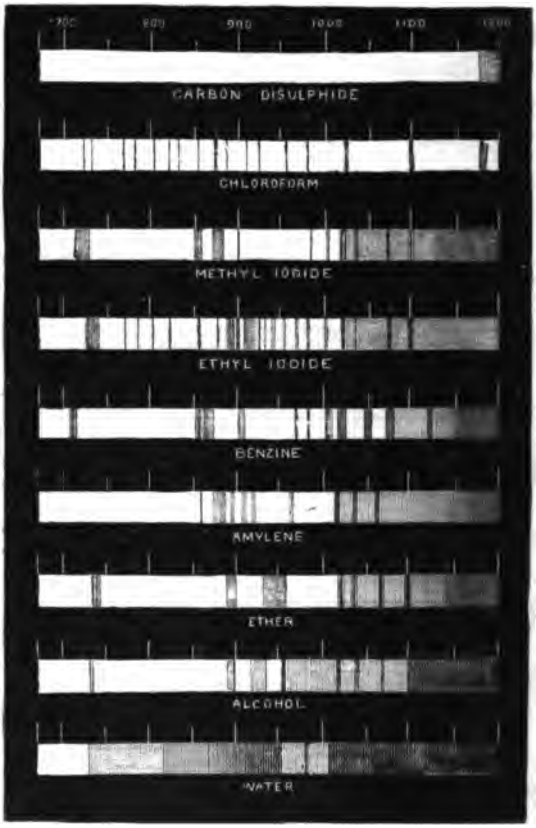
Becquerel's Phosphorescent Phonogram of the Infra-red.

of phosphorescent matter will excite a neighbouring one to a certain degree.

It seems curious that this dark region of the spectrum should have been so little explored, but no doubt this has arisen from the difficulty which has existed in finding any accurate and delicate plan of so doing. Thanks, however, to photography, not only can general information as to the energy of radiation to be found there be recognized, but

also the energy that is absorbed in passing through our atmosphere, and the causes to which the absorption is due. Abney and Festing found that most colourless liquids

Fig. 118.



Absorption Spectra in the Infra-red.

showed marked absorption bands in the infra-red of the spectrum, tracing them only, however, in compounds in which hydrogen existed. A few of these absorptions are given in Fig. 118.

It will be seen that these organic compounds all cut off

radiation in marked and definite positions. Particular attention, however, should be given to the spectrum due to the absorption by water, alcohol, and benzine, kindred absorptions to these having been found in the solar spectrum. To the first indeed may be allotted the principal absorptions taking place in this region. Fig. 119 gives a comparison of the thermograms of solar radiation, taken with the thermopile and the bolometer, and also a thermogram of the absorption of water as shown by the thermopile. This latter was a confirmation by Abney and Festing of the photographic results they had obtained in 1882.

There are also well-marked absorptions apparently due to some benzine compound and to an ethyl compound to which alcohol belongs, and these seem, according to Abney and Festing, to be placed beyond the limits of our atmosphere. Hence wherever we are led to locate them it must be in some region in which the heat is not sufficient to drive them into their component elements.]

59. The Ultra-Violet Spectrum.

After the heating powers of the infra-red rays had been discovered by Sir William Herschel, the question naturally arose whether there was not a similar prolongation of the spectrum beyond the visible limit of the violet rays, which, though invisible to the eye, might yet betray its existence in some indirect manner. This question engaged the attention both of Wollaston and Inglefield. The latter discovered as early as 1803 that the violet end of the spectrum had a powerful influence in bringing out phosphorescence in certain substances, and drew attention to the fact that Scheele had observed in 1777 that it quickly blackened chloride of silver, whence he inferred that the influence extended beyond the visible end of the violet. Ritter, of Jena, was

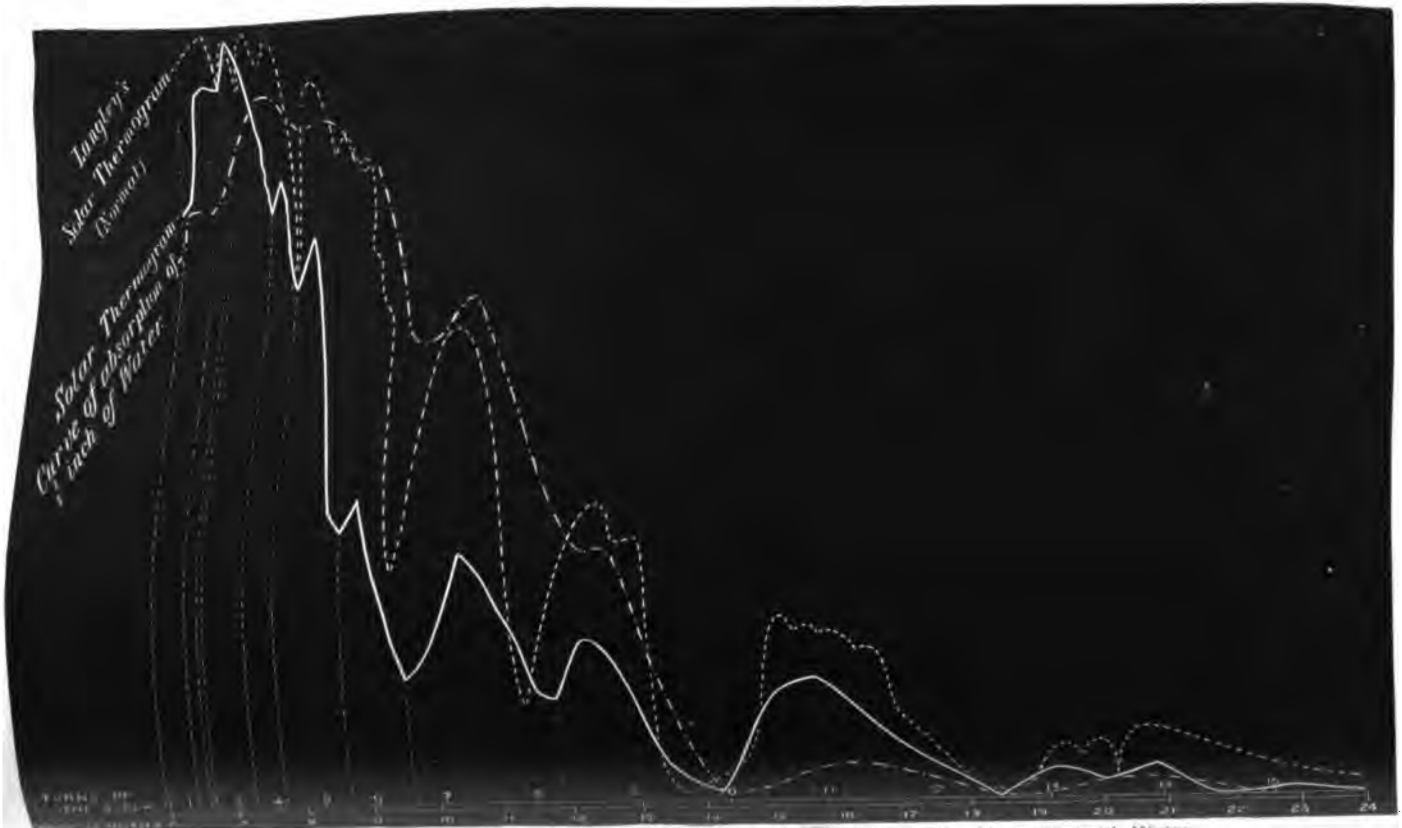


Fig. 119. Thermograms of the Normal Solar Spectrum and Comparison of the Absorption with Water.

the first to demonstrate this by experiment, and in these researches he was succeeded by Wollaston. In 1840 Sir John Herschel published his experiments upon the chemical action of the spectrum, in which he remarks that the rays of most intense action were those lying beyond the visible violet. Inactive spaces—analogous to the dark lines—he failed to discover, though sought for by means of sensitive paper prepared by Talbot's process. He states that the ultra-violet rays are not always absolutely invisible, but some at least may be occasionally perceived as a lavender-grey tint.

The inactive spaces in the chemically-impressed spectrum were first discovered by Becquerel in 1842. From a very pure flint-glass prism a spectrum was formed and thrown on to a screen by a lens placed immediately behind the prism, and a tenth of an inch from the slit by which the light entered. The screen, which was eighty inches from the lens, was arranged so as to receive the substances which were to be submitted to the action of the rays, such as photographic paper, salts of silver, etc. After exposures of various duration, there appeared numerous lines indicating places of minimum chemical action. These were found to correspond exactly with the dark lines between A and H in the visible spectrum as far as that spectrum extended. Beyond H, however, in the chemically-impressed spectrum, there appeared a great number of such lines designated by Becquerel with the letters T, K, etc. Such lines are shown in Draper's tithonographic spectrum (Fig. 109), even beyond P. It was found by Stokes that ordinary glass absorbed a very considerable portion of the ultra-violet rays, and that of all substances quartz was the most transparent for these rays, and after that Iceland spar. He therefore selected a prism and lens of quartz for his investigations, and by this means reached beyond P, even to the Q-line. By using a quartz

prism and the elimination of all stray light, Helmholtz succeeded in viewing the lines shown to exist in the ultra-violet spectrum by Becquerel and Stokes. Seculic accomplished the same result by allowing the sun's direct rays to fall on the prisms. When the spectroscope was so placed that the sun's rays fell directly on to the refractive surface of the prism, the spectrum could be traced as far as the N-line. The group M was so distinctly visible that even the third line was not too faint for measurement, but the N-lines were somewhat indistinct and washed out. The colour of this part of the spectrum was light blue and silver grey.

In accordance with the impressions produced upon our senses, we are accustomed to divide the solar rays into light, heat, and chemical action. These three different effects are not to be regarded as the result of three different kinds of rays, but rather as different effects of the energy inherent in the ether vibrations. According to the length of the waves and the nature of the receiving particles, this energy shows itself either as heat, light, or chemical action. Those waves varying in length from 768 to 369 millionths of a millimetre act upon the nerves of the eye and produce the sensation of light, the various colours depending exclusively upon the different rates of the ether vibrations. The waves of greatest length produce the impression of red, and as the waves gradually decrease in length the eye perceives in succession all the remaining colours, orange, yellow, green, blue, indigo, and violet, in the same order as they appear in the solar spectrum.

In this scale of colour whilst ascending from green towards violet, light begins to exhibit an additional property, that of setting free certain molecular combinations, and of originating chemical action, or of changing the molecular condition on the surface of certain substances, bringing into existence new waves of light.

In the opposite direction from green to red, as the waves increase in length the action of the light changes in character * and assumes the form of mechanical force, exciting in the increased molecules vibratory motion, which is shown by a rise in temperature of the body. These waves extend far beyond the boundary of the red, and form there, as it were, a second and invisible spectrum.

There exists, therefore, in light but one form of wave motion, although the waves are of varying length. The solar rays, whether producing chemical action, light, or heat, do not differ one from the other more than yellow light does from green, or green from violet. In no part of the spectrum is it possible to separate the light rays from the heat rays, or to set aside the one and deal with the other, for light and heat rays of the same refrangibility are completely identical. The light rays may undoubtedly be separated, and with them their own heating effect, from the invisible rays, because they possess a different refrangibility; but if at any part of the spectrum the light rays are removed, the capacity for that part of the spectrum to heat is at the same time eliminated.

The chemical action of the rays is after all as truly of a mechanical nature as that of the heat rays, and can be expressed equally in units of mechanical force. Moreover, the expression "chemical rays," if applied solely to the violet and ultra-violet rays, is not distinctive, for although these rays are pre-eminent in their influence upon salts of silver and chromic acid, they possess no power upon vegetable life.† According to Lommel's investigations upon fluorescence, every ray that is absorbed can produce chemical action;

* [There is no *real* change in character; every ray will heat a substance in a greater or less degree. See Langley's bolometric spectrum.]

† [This is hardly correct.]

different substances absorb different rays; in some chemical action is produced by the red and in some by the violet rays. The curve I, K, L (Fig. 108), representing the so-called *chemical* intensity of the solar spectrum, refers only to the chemical effect such rays have upon certain chemical combinations. In the process of assimilation carried on by plants, namely the decomposition of carbonic acid and the liberation of oxygen, the most active rays, and those most plentifully absorbed by chlorophyll, are those which possess at the same time considerable capacity for doing mechanical work. These are the red rays between the dark lines B and C. The blue and the violet rays, although powerfully absorbed, do not exert so great an influence on account of their feebler energy. The extreme red rays, notwithstanding they carry greater energy, produce no effect, as they are not in general absorbed. For the same reason the yellow rays, though possessing considerable capacity for doing work, have scarcely any influence, the quantity absorbed being very small; and the same may be said both for the orange and the green rays. The total mechanical work which can be done by the ether waves is the true measure of their energy.*

60. The Ultra-violet Spectrum and Fluorescence Spectra.

If an aqueous infusion be prepared from the bark of the horse-chestnut (*Æsculus hippocastanum*), and placed in a glass vessel, a cone of white light sent through the colourless liquid by a lens will appear of a splendid blue colour. In a similar manner, if the cone of light be sent through the colourless solution of quinine in extremely dilute

* [The heating effect on a body of any ray is the true measure of its energy.]

sulphuric acid, the liquid will appear of a bright blue, especially at the upper surface. Fluor spar (calcium fluoride), itself of a greenish colour, appears a violet blue when placed in the path of the light. From this mineral the term *fluorescence* has been given to the whole class of similar phenomena. The phenomenon was first made the subject of serious investigation by Sir John Herschel and Sir David Brewster; by the former the appearance was regarded as affecting only the surface of certain liquids, and received from him the name of "epipolic dispersion;" by Brewster fluorescence was believed to affect the whole cone of light, although showing brightest at the surface. Further observations of a more elaborate nature were published in 1852 by Professor Stokes, by whom the term fluorescence was proposed. From numerous experiments he showed that, under the influence of light, fluorescent substances became self-luminous, and emitted light of a refrangibility differing from that by which they had been rendered luminous. He announced it as a universal law that the refrangibility of fluorescent light is never greater than that of the light by which it has been excited. This law, though confirmed by Hagenbach, has been found by Lommel to be open to considerable exceptions.*

For the examination of the rays to which fluorescence is due, and for the investigation of the changes in refrangibility wrought in light by this phenomenon, the test by the spectroscope is of the greatest value. For this purpose a fluorescent liquid—such as a clear solution of quinine—is placed in a long glass vessel with parallel sides, and upon the surface of the liquid a solar spectrum is projected. It will be found that the end of the spectrum towards the red is wanting, inasmuch as the less refrangible rays, as far per-

* [These exceptions have been disputed by various experimenters, and at present we hold to Stokes's law.]

haps as G,* pass unhindered through the liquid. From G onwards there is a spectrum band of dispersed light which extends not only to H, but far beyond, and in this ultra-violet portion many dark lines are visible. By Stokes these lines were designated by letters proceeding from L to S.

According to the nature of the liquid the fluorescent spectrum commences more or less near the red; with a watery infusion of horse-chestnut bark it begins to be visible between F and G; with tincture of thorn-apple the dark line F can be seen. As a rule it is the highly refrangible rays that cause the strongest fluorescence, but the less refrangible rays may sometimes produce it most intensely. If, for instance, a glass trough be filled with a solution of naphthaline red in alcohol, and a solar spectrum projected upon it, the fluorescence begins to appear in the red between C and D, is very intense beyond D, and extends a long way into the ultra-violet. The yellow-green rays are also extremely fluorescent.

When sunlight is used the dark lines in the ultra-violet portion of the spectrum are always visible, whatever may be the fluorescent substance; with the electric light, on the contrary, they are never present, although this light contains rays of higher refrangibility than sunlight. From this it follows that these dark absorption bands are peculiar to the solar spectrum, and are not the effect of absorption in the fluorescent substance.† The effect produced upon light ‡ by fluorescent substances is, as Professor Thomson has pointed out, that of degradation; the ether vibrations which are too rapid to affect the eye become so modified in speed as to

* [H and K can be photographed through a solution of quinine.]

† [Perhaps a still better proof is that these lines may be photographed without the aid of fluorescence.]

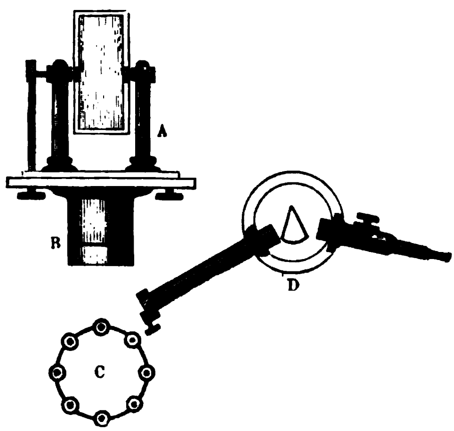
‡ [The fluorescent substances become fresh sources of light; the original vibrations are expended and give rise to new vibrations.]

give the impression of light. When the lenses and prisms are of quartz the ultra-violet spectrum is not only much brighter, but also considerably longer, extending even to the line R, while with glass prisms it never extends beyond N.*

It is possible therefore, by introducing a fluorescent substance in the path of the spectrum rays, so to diminish the refraction of the invisible ultra-violet rays that they shall produce upon the eye the effect of light.

A trivial deviation in carrying out the experiment of sending a cone of light through an aqueous solution of

FIG. 120.



Professor Morton's Apparatus for Fluorescence.

horse-chestnut bark was the means of revealing an important fact. It was found that if a second solution was placed in the path of the light before it entered the lens, the light had no power to cause fluorescence in the first solution; and this is true of every fluorescent substance. Whence it follows that fluorescence is produced by the same rays that are absorbed by the fluorescent substance; as

* [This is not quite exact. With pure white flint-glass prisms the furthest lines in the solar spectrum can be photographed.]

pointed out by Stokes, fluorescence is the counterpart of absorption. Hence the fluorescent spectrum of a substance is brightest in those parts which are darkest in the absorption spectrum of the same substance.

FIG. 121.

Table arranged with Glasses for Observations of Fluorescent Substances.

The observations published by Professor H. Morton, of Hoboken, directed chiefly upon the various compounds of uranium, exhibit very distinctly the connection between fluorescence and absorption. His method of work was as follows. By the heliostat mirror A (Fig. 120) he directed sunlight upon the flat surface of a glass vessel containing the fluorescent solution, the various solutions being arranged upon a small table as shown in Fig. 121. The fluorescent light reflected from the glass vessels was then analysed by a spectroscope in the usual manner.

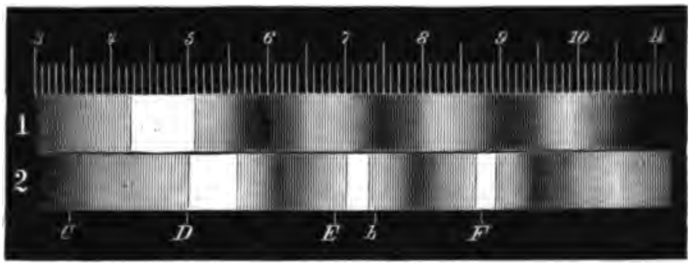
Some of the results of Professor Morton's work will be found in the accompanying wood-cuts, in which the corresponding spectra emissive (fluorescent) and absorptive are given for a number of the compounds of uranium. Figs. 122 and 123 exhibit the fluorescent and absorption spectra of Thallin and Petrolucene.

Figs. 124 and 125 give the spectra of normal acetate of

uranium in three conditions, Nos. 1 and 2 with and without water of crystallization, No. 3 with uranyl-sodium acetate.

Figs. 126 and 127 represent the fluorescent and absorption spectra of three other compounds, No. 1 that of arsenate of

FIG. 122.

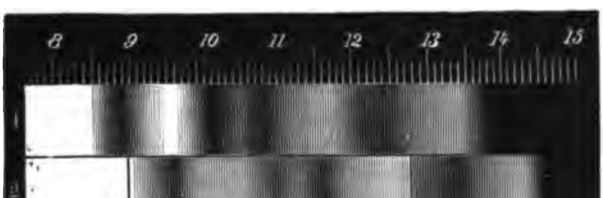


Fluorescent Spectra of Thallin (1) and Petrolucene (2).

uranium, No. 2 that of sodium-uranylic carbonate in a solid state, and No. 3 of the same in solution.

Figs. 128 and 129 give the companion spectra of

FIG. 123.



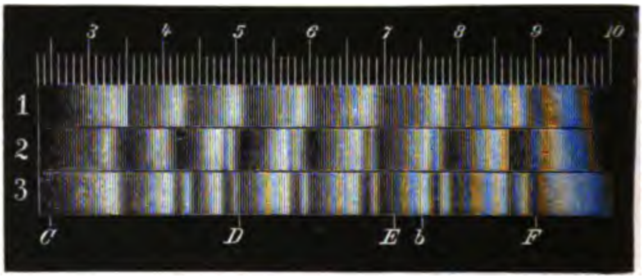
Absorption Spectra of Thallin (1) and Petrolucene (2).

the following substances, No. 1 that of uranic monophosphate solid, No. 2 in solution, No. 3 of di-uranic-phosphate.

Fig. 130 gives the fluorescence spectra No. 1 of normal ammonium-uranyl-sulphate, No. 3 of the same without water of crystallization, No. 2 a mixture of the same, No. 5 of ammonium-diuranyl sulphate, No. 4 of a mixture of both.

Among the substances highly fluorescent in solution even when in minute quantities may be mentioned saffron (in spirit, red-brown); naphthalin or magdala-red (in spirit, vermilion); eosin or tetra-bromine phtalein (in water, greenish);

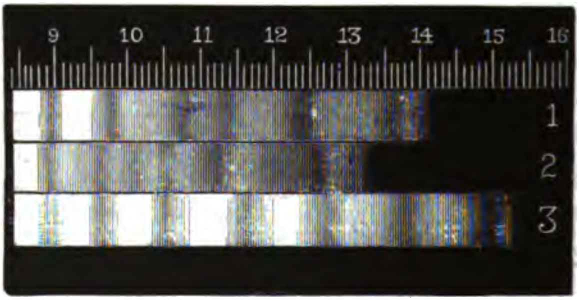
FIG. 124.



Fluorescent Spectra of Normal Acetate of Uranium (1 with, 2 without Water of Crystallization), 3 of Sodium-uranium-acetate.

fluorescin or phtalein-resorcin (in ammonia, bright green); extract of log-wood (in spirit with alum, clear dark green);

FIG. 125.



Absorption Spectra of Substances named in Fig. 124.

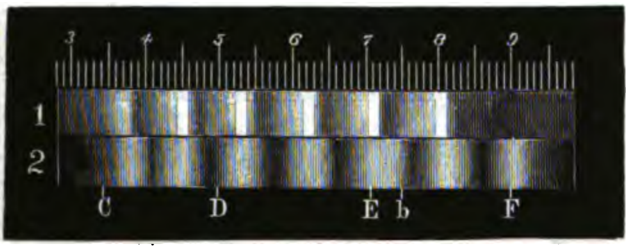
horse-chestnut bark (in spirit, bright blue); di-chlor-anthracene-sulphonic acid (in water, brilliant light blue); sodium di-chlor-anthracene-disulphonate (in water, dark blue).*

* [Almost all of the aromatic series exhibit fluorescence when the beam of the electric light is concentrated on them, the fluorescence

61. Soret's Fluorescence Eye-piece.

By the following arrangement Soret brings to view the ultra-violet rays without projecting the spectrum upon the

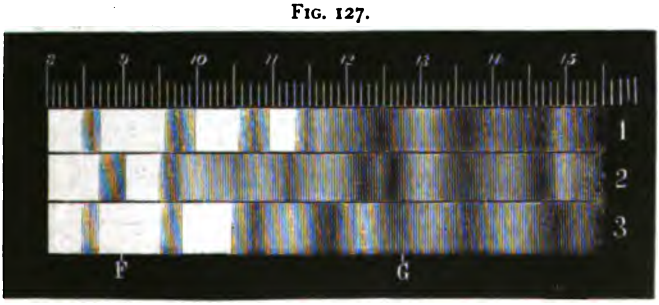
Fig. 126.



Fluorescent Spectra of Arsenate of Uranium (1) and of Sodium-uranylic-carbonate (2).

surface of a fluorescent solution. A stratum of a fluorescent solution is placed in the focus of the telescope lens of a spectroscope, and the spectrum viewed by an eye-piece turned towards the axis of the observing telescope.

Fig. 127.



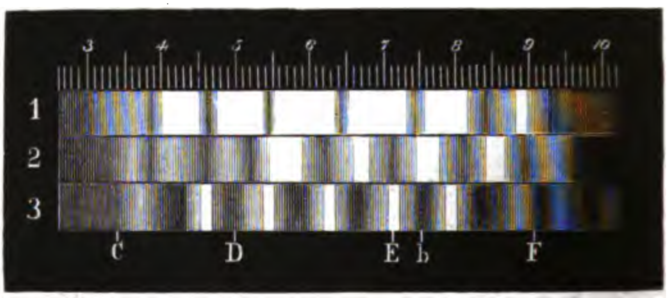
Absorption Spectra of Substances named in Fig. 126.

This contrivance can easily be applied to an ordinary

taking place far up in the ultra-violet. The researches of Hartley and Huntingdon on the absorption spectra in the ultra-violet of a variety of substances indicate the locality where the fluorescence may be expected. If a fluorescent eye-piece be filled with these various liquids, the fluorescence can be readily seen when lenses and prisms are constructed of Iceland spar or quartz.]

spectroscope. The eye-piece is removed and replaced by one that might be termed a fluorescence eye-piece, of which a vertical section is given in Fig. 131. It consists firstly of the brass slide *a b c d*, composed of the ring *b d* soldered on

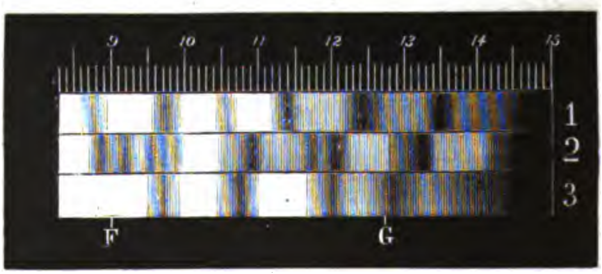
FIG. 128.



Fluorescent Spectra of Uranic-Mono-phosphate (1 solid, 2 in Solution), 3 Di-uranic-phosphate.

to the tube *c d*, which slides into the tube L L of the observing telescope, carrying with it the plates holding the solution; secondly of the slide *e g i k*, composed likewise of a ring, but of a smaller diameter than the ring *b d*, and which

FIG. 129.

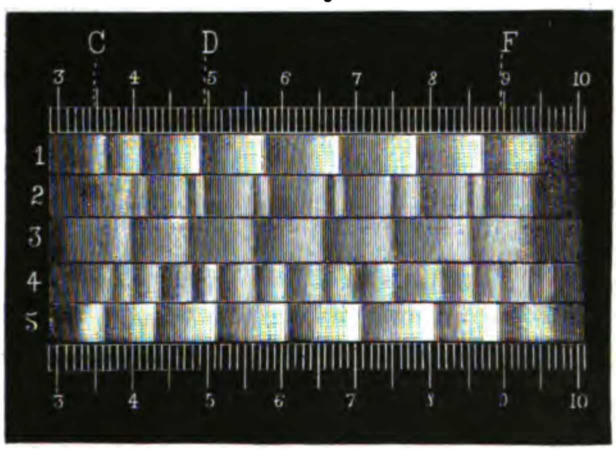


Absorption Spectra of Substances named in Fig. 128.

is soldered to the end of the tube *g k*. The ring *e i* is concentric to the ring *b d*, to which it is attached by the ends of two screws (not visible in the figure) at opposite points of the horizontal diameter of both rings, so that they form one

axis at the point *o*. The slide *e g ι k* revolves on this axis, and can be directed towards the principal axis of the observing telescope of the spectroscope. By means of a clamp (omitted in the drawing) the slide *e g ι k* may be secured in any position. In the tube *g k* of the movable portion an ordinary eye-piece is introduced—that of the spectroscope if of suitable focal distance—and so adjusted as to show clearly the fluorescent stratum. To answer the

FIG. 130.



Fluorescent Spectra of Ammonium-uranyl-sulphate 1, of the same without Water of Crystallization 3, of a Mixture of both 2, of Ammonium-di-Uranylic-sulphate 5, of a Mixture of both 4.

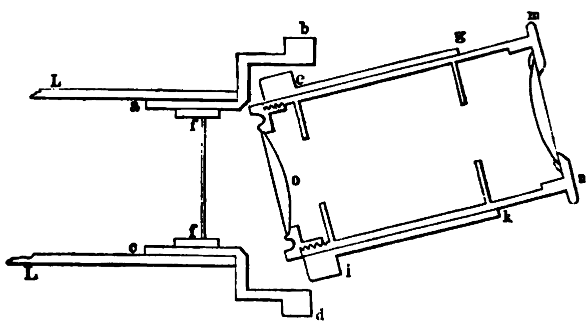
purpose of cross wires two fine lines may be traced by a diamond upon the glass plates holding the liquid. In order to bring the fluorescent solution to the focus of the object-glass, the eye-piece tube must be made to slide sufficiently far into the tube of the telescope.

The fluorescent object may consist either of uranium glass or of fluorescent liquids confined between two very thin sheets of glass separated about the twentieth of an inch.

If the solar spectrum is the object of investigation, a ray of

light must be directed on to the slit by a lens of great focal length, if possible one of quartz. It is also advantageous to eliminate the brightest rays by means of a blue glass.* The eye-piece *m n o* (Fig. 131) is then brought to its usual position, with the axis coincident with that of the telescope, and directed upon the most refrangible part of the visible spectrum. The presence of the fluorescence stratum in no way hinders the examination of the visible spectrum, in which the Fraunhofer lines appear with great distinctness. In this position of the eye-piece the fluorescent spectrum formed from the glass plate is also to be seen, but to study it

FIG. 131.



Soret's Eye-piece for Observations of Fluorescence.

minutely the eye-piece must be inclined as shown in the figure. The visible part of the spectrum is then removed from sight, and the fluorescence spectrum alone occupies the field; it appears of one tone of colour traversed by dark lines, the position of which may be determined by the crossed lines scratched upon the glass.

Soret's investigations extended over a great variety of

* [With the solar spectrum the blue glass may be used, seeing the glass cuts off scarcely any of the ultra-violet solar rays. If the electric light be examined, the most refrangible rays would be absorbed.]

fluorescent substances. With uranium glass the fluorescent spectrum was clearly visible at the line *b*, was very intense at H, but became indistinct beyond M, although the four lines at M could be recognised. A weak solution of horse-chestnut bark gave the most intense spectrum, in which even the line O was visible. A weak solution of naphthaline (red magdala) gave a less satisfactory spectrum in the ultra-violet beyond M, but presented a remarkable appearance in the portion of the spectrum corresponding to the visible rays, inasmuch as all the lines were clearly to be seen from near D as far as M.

By the help of this eye-piece Soret was enabled to obtain valuable results with regard to the ultra-violet rays of the spectrum and other phenomena of absorption, the study of which had hitherto been almost exclusively confined to the visible rays. When direct sunlight was not used the electric spark was employed from a large Ruhmkorff induction coil. The electrodes in most frequent use were of cadmium, for the principal lines of which Mascart had determined the wave-lengths. Zinc was sometimes used in conjunction with cadmium, as also iron, in which case the bright lines were so numerous as almost to create a continuous spectrum upon which the cadmium lines stood out with great prominence. With electrodes of aluminium lines appeared of higher refrangibility even than with zinc.

The lenses of the collimator and the telescope were of quartz, with a focal length of about 13½ inches for the D-lines. The prisms were also of quartz with a refracting angle of 60°, the refracting angle being perpendicular to the axis of the quartz. The fluorescent substance in the eye-piece was generally an aqueous solution of horse-chestnut bark, confined between plates of glass and quartz, the quartz being turned towards the incident ray; under these conditions fluorescence is much stronger than with uranium glass.

The substance whose absorption spectrum was to be examined was placed in front of the slit, or if the condensing lens was removed, near to the spark. The absorptive liquid was enclosed either in a glass vessel with sides of quartz, or in a glass tube about four inches in length, the ends of which were closed with plates of quartz. The liquids to be examined were in every case less than half an inch thick. In these observations Soret contented himself with dividing the spectrum into 32 parts, the first 25 divisions being marked off by the principal lines of cadmium as determined by Mascart. Although line 26 belongs to cadmium, it is not included in Mascart's measurements. Lines 27, 28, and 29 are the last three of zinc, and lines 30, 31, and 32—the last a double line—are the last three of aluminium. The first seven lines are bright, the eighth is ill-defined and belongs probably to the air; it is a little more refrangible than H of the solar spectrum.

Fig. 132 shows a map of the absorption lines for the violet and ultra-violet portions of the spectrum. A table is furnished by Soret* of a great number of substances in which it is stated which rays the substance transmits, which it transmits in part, and which it wholly absorbs.

A comparison has been instituted by Soret between prisms of quartz and Iceland spar, to test their relative transparency, and it was found that in general quartz was the most transparent. Iceland spar, therefore, should only be employed when the refrangibility of the rays does not exceed that of the lines of cadmium.

62. Photographic Representation of Spectra.

The value of a photographic picture of the spectrum of the sun or of any of the heavenly bodies does not depend solely on the circumstance that the individual lines are auto-

* "Archives des Sciences Physiques" (Geneva 1878).

matically reproduced with perfect truth, but also on the fact that the ultra-violet and invisible part of the spectrum is also fully represented. The unequal chemical effect of the different rays, however, presents so many difficulties to their photographic reproduction that it is impossible to obtain all portions with the same sharpness. A cause of this also lies in the fact that to obtain a photographic image of the ultra-violet rays, a quartz lens which is not achromatic is necessary:* with a lens of this kind the focal length varies according to the rays. The more refrangible rays have a shorter focus than the less refrangible, so that only a very small part of the spectrum can be distinct at once upon the photographic plate.† On this account Müller could only obtain a photographic picture of the solar spectrum by taking the ultra-violet part in a number of separate portions, each at different focal distances and with different exposures, the whole being afterwards put together. In this spectrum there are sixty dark lines of higher refrangibility than H; still the extreme end is somewhat ill-defined.

FIG. 132.—Soret's Diagram of Absorption Lines.

* [Only for the very extreme ultra-violet rays.]

† [This is because the usual camera employed is unsuited. If an

Rutherfurd proceeded in a similar manner. As in an ordinary object-glass, even when achromatic, the optical and chemical foci are never coincident, the photographer is compelled to find by experiment the point at which the chemical rays unite, or with the solar image, the point at which the *chemical* image * of the sun is formed. In a telescope of 8 feet 2½ inches focal length, the distance between the optical and chemical foci † may amount to half an inch, and in a telescope whose focal length is 14 feet 2½ inches, this distance may be as much as ⅞ of an inch. But even when the chemical focus is discovered there remains a certain amount of aberration disregarded by the optician in the construction of the instrument, which prevents the use of a high magnifying power. To overcome this difficulty Rutherfurd had a telescope constructed the lens of which was specially corrected for the chemical rays, and which, though unfit for the ordinary work of a telescope, enabled him to obtain excellent photographic images. To such a telescope he adjusted the spectroscope, and to the latter appended a photographic camera without an object-glass. He displaced the eye-piece so far that it acted as an object-glass and formed the direct image of the spectrum with its lines on the photographic plate. The photograph was then taken in the usual manner. The spectrum was divided into fifteen portions, and when put together the length was 6 feet 11 inches. As glass prisms were employed, the spectrum extends but little beyond the line H. If any portion of this photographic spectrum be compared with the

arrangement is made by which the plate can be tilted at an angle between 30° and 50° to the axis of the lens, the whole of the blue, violet, and ultra-violet can be brought to a good focus.]

* [The reader must take this title *cum grano salis*. A chemical image is a misnomer.]

† [The focus depends on the refractive index of the rays which are most photographically active.]

same portion in Kirchhoff's and Ångström's maps, it will be found that though in the photograph none of the visible lines are absent, yet many other lines which are wanting in the maps are present.

By means of one of Nobert's diffraction gratings, and by the use of prisms and lenses of Iceland spar, Mascart * succeeded in photographing the ultra-violet part of the solar spectrum as far as T, and in ascertaining the wave-lengths of the lines, which numbered about three hundred. The following table gives the measures of the principal lines, with the exception of A, S, and T, which he was unable to include in the spectrum.

Visible Spectrum.			Ultra-Violet Spectrum.		
Ray or Line.	Index of Refraction of the ordinary Ray for Iceland Spar.	Wave-length in 10 Millionths of a Millimetre.	Line.	Index of Refraction of the ordinary Ray in Iceland Spar.	Wave-length in 10 Millionths of a Millimetre.
A	1·60513	——	L	1·68706	3810·0
B	1·65296	6866·7	M	1·68966	3728·8
C	1·65446	6560·7	N	1·69441	3580·2
D	1·65846	5888	O	1·69955	3440·1
E	1·66354	5267·8	P	1·70276	3360·2
b	1·66446	5165·5	Q	1·70613	3285·6
F	1·66793	4859·6	R	1·71155	3177·5
G	1·67620	4307·5	S	1·71580	——
H	1·68330	3967·2	T	1·71939	——

In Mascart's drawing the lines are placed according to the amount of deviation given by the prisms. It extends further into the ultra-violet portion of the spectrum than any previous work, but its value is impaired by the adoption of an arbitrary scale. A more complete map has been made by Cornu,† given in Plate XII. Owing to the employment of ordinary crown and flint-glass prisms, the spectrum is not carried so far into the ultra-violet portion as Mascart's

* *Ann. sc. de l'école norm. sup. Paris* 1864, No. 5.

† *Ann. sc. de l'école norm. sup. Paris* 1874, No. 12.

drawing, but the result seems to prove that prisms and lenses of glass are better adapted to the investigation of the ultra-violet spectrum than has generally been supposed. The absorptive influence of the glass does not prevent the diffraction spectrum from being photographed as far as P or even Q; with a prism of Iceland spar the photograph reached to P, with ordinary flint glass to O. Cornu's drawing of the ultra-violet spectrum may be regarded as a direct continuation of Ångström's spectrum; it is treated in precisely the same way, and the constants are taken from Ångström's numbers.

With the same object in view,—namely, completing Ångström's work,—a series of accurate measures and a vast number of photographs have been undertaken by Professor Vogel of Potsdam in conjunction with Dr. Lohse. These photographs extend from F to H—from 489 to 389 millionths of a millimetre of wave-length—and are each about thirteen inches in length. The details of observation have been published by Dr. Vogel in No. 3 of the *Astrophysical Observations at Potsdam*, in which he has given the results of his experience with regard to photography as to length of exposure, width of slit, etc. The length of exposure was mainly affected by the condition of the sky; a slight veil of cloud had but small influence upon the portion of the spectrum lying between F and G, while at H it necessitated a double exposure. The greatest hindrance came from cirrus clouds; the presence of cumuli had scarcely any effect upon the unclouded parts of the sky. The width of the slit is of the greatest importance; it must not be diminished beyond a certain point: the most advantageous width proved to be 0·008 mill. The measurement of the lines from the photograph was accomplished by means of a special instrument consisting of a compound microscope mounted with a micrometer screw. The graphic reproduction of the

photographs was the joint work of Professor Vogel and Dr. Müller. Great attention was given to the exact rendering of all the details contained in the photographs which could not be described by letterpress or by numbers. "In really good negatives, where the exposure had been exact," remarks Professor Vogel, "the space between the bright—in reality dark—lines does not appear uniformly black, but shows remarkable variations in intensity. In some places the impression produced is as if the depth of the dark background was modified by the presence of a system of excessively fine bright lines; in other places there is no trace of any such system of lines, but upon a neutral shaded background *dark* lines were distinctly visible. These dark lines, which represent *bright* lines in the solar spectrum, excited my notice in some of the earliest good photographs, and became the object of my special attention. Such places in the spectrum which were remarkably dark and had the appearance of lines were represented by dotted lines or rings. It must be expressly stated that great caution was used on this point, and only places so represented where there was satisfactory evidence that the effect of dark lines was produced neither by contrast with the neighbouring bright lines nor by uniformity at a spot occupied by an intermittent system of lines.

"With instruments of moderate power bright lines have often been thought to appear in the solar spectrum in the neighbourhood of *b*, and also, when the sun is low, near D. The appearance is produced by a system of fine lines which are atmospheric in their origin, and which are arranged in groups, the intermediate space being remarkably bright. A greater dispersive power reveals at once the nature of the phenomenon.

"It appears, however, that there are really bright lines in the solar spectrum, and as far as I know Cornu was

the first to draw attention to the fact. Upon the plate (Plate XII.) which accompanies his investigations upon the violet portion of the spectrum the position of the lines is more definitely pointed out (wave-length 388·15 and 388·55)."

Professor Henry Draper of New York obtained a photograph of the diffraction spectrum of the sun, which he reproduced by means of the Albertotype process, extending from wave-length 4205 to 3736.

A number of excellent photographs have been taken of the spectra of the metals and gases by J. Rand Capron, by means of a simple apparatus consisting of a Browning spectroscope of five prisms and a small camera. The spectra of the metals were obtained sometimes by the spark, and sometimes by the voltaic arc. The spark was produced by a large Ruhmkorff coil, and the exposure varied up to fifteen minutes. The arc was formed by a Grove battery of forty elements. The electrodes, metal in the form of powder, and in some cases of solid metal. With the arc the exposure varied from three to five minutes. When the spark was used the spectrum of the air appeared with few exceptions together with the lines of the spectrum, but these latter were easily distinguished, as they were always shorter than the breadth of the spectrum, while the air-line spectrum traversed it entirely. In many of the photographs the air spectrum is the most prominent feature, and forms a scale by which to estimate the position of the lines of the metals. When the arc was used some carbon lines appeared, but these were of service as fixed points for the comparison of spectra.

While Rand Capron was occupied with the practical object of facilitating the recognition of an element by means of its spectrum, Lockyer * was engaged upon the application of spectrum photography to the advancement of science.

* [Lockyer had commenced his photographic work some time before Rand Capron.]

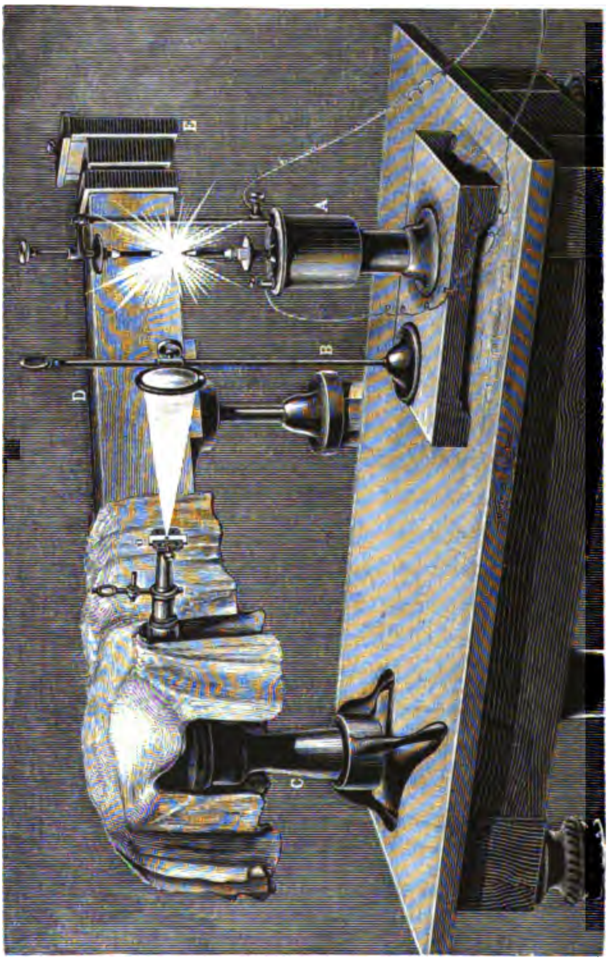
By the photographic record of the spectra of metals in which the length of the lines (Fig. 81) was seen to vary according to the temperature and density of the incandescent vapours, he sought to obtain data whereby to infer the physical constitution of the sun, and the causes of the various types of the stars. The facts thus collected would also be available for testing the purity of substances, for ascertaining the ingredients of alloys, and above all for investigating the molecular constitution of the non-metallic elements and gases. The records of these observations are to be found in Lockyer's work, "Studies in Spectrum Analysis.*

In conducting this research it was necessary to photograph various spectra on the same plate and to bring them into comparison with the solar spectrum. The manner in which this was accomplished is shown in Fig. 133. Upon a solid table rests the heavy stand C, carrying three prisms of an angle of 45°, and one of an angle of 60°. These are so adjusted that the light on emerging from them is directed through the camera at D on to the sensitive plate E. The prisms are protected from side light by a black cloth thrown over the instrument. The camera D contains a quartz lens of 2 inches diameter and about 5 feet focal length. By the use of the electric light or the solar rays a sharp image of the spectrum, extending from the wave-length 3900 to 4500, is formed on the sensitive plate E. A is the electric lamp, with the arc between the carbon points. When sunlight is required the carbon points are replaced by a bi-convex lens, upon which the solar rays are directed from a heliostat; a second convex lens B throws the image of the sun or voltaic arc upon the slit *o*.

* [This work gives merely an outline of Lockyer's work up to 1878. An account of his later work must be sought for in the *Proceedings and Transactions of the Royal Society*.]

To facilitate the comparison of various portions of spectra, and to record them photographically on the same plate, the slit must be so arranged that different sections of it may be

FIG. 133.

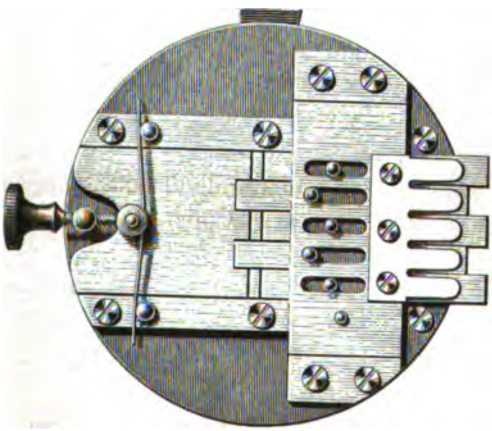


Lockyer's Apparatus for the Simultaneous Exhibition of the Spectra of Various Sources of Light.

illuminated *in succession.* The slit so constructed by Lockyer is shown in Fig. 134, where arrangements are made for obtaining five photographs. The slit is covered by a brass

sliding plate $2\frac{3}{4}$ inches long by $1\frac{3}{8}$ inches wide, in which is an opening of $\frac{1}{5}$ of an inch in depth, which leaves a corresponding part of the slide uncovered. In the sliding plate is a small pin, and in the plate of the slit is a succession of depressions, so that the motion of the first plate is stopped whenever the pin falls into a depression. The distance between the depressions corresponds exactly to the width of opening in the sliding plate, so that the plate is moved forward each time to the extent of the exposed portion

FIG. 134.



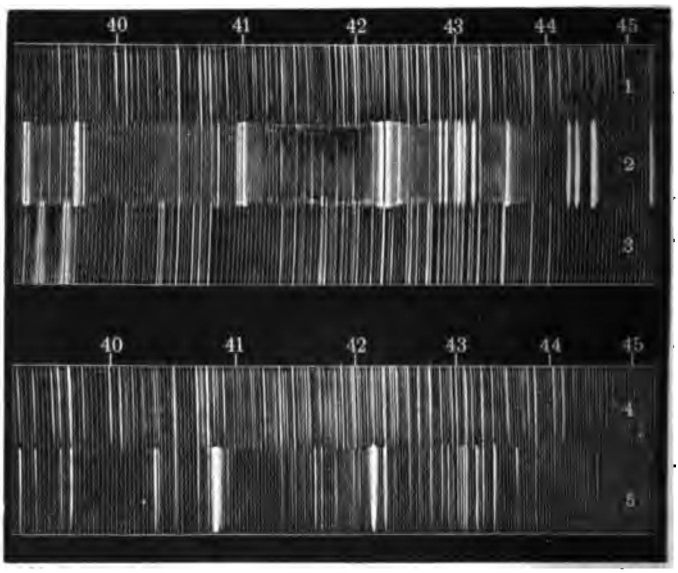
Slit for the Reception of the Spectra of Various Sources of Light.

of the slit, and thus the spectra to be compared are all brought into immediate contact. In the figure two portions of the slit are covered; by means of the uncovered parts, therefore, it would be possible to photograph from three different sources of light. If the slit is opened to its full extent, a spectrum will be obtained answering in width to the length of the slit; if only one division of the slit is opened, there will be formed upon a corresponding portion of the plate the spectrum of the metal which is being volatilized. If this division is closed and the next opened, and another

metal placed in the flame, its spectrum will be received on the same plate in immediate proximity to the first spectrum.

By this means Lockyer has photographed the spectra of a great number of metals, and made it possible to institute an exact comparison between them and the solar spectrum. Examples of his work are given in Figs. 135 and 136. In

Fig. 135.



Photographed Spectra of Metals.

Fig. 135, No. 1 is the spectrum of the Lenarto meteorite; No. 2 the spectrum of cadmium; No. 3 that of aluminium; No. 4 that of iron—nearly pure; No. 5 that of strontium; in Fig. 136, No. 1 is the spectrum of barium; No. 3 that of calcium; and the central one, No. 2, is the solar spectrum.

63. The Application of the Spectroscope to the Bessemer Process.

One of the most important applications of the spectroscope to technical industry is in the manufacture of cast steel by

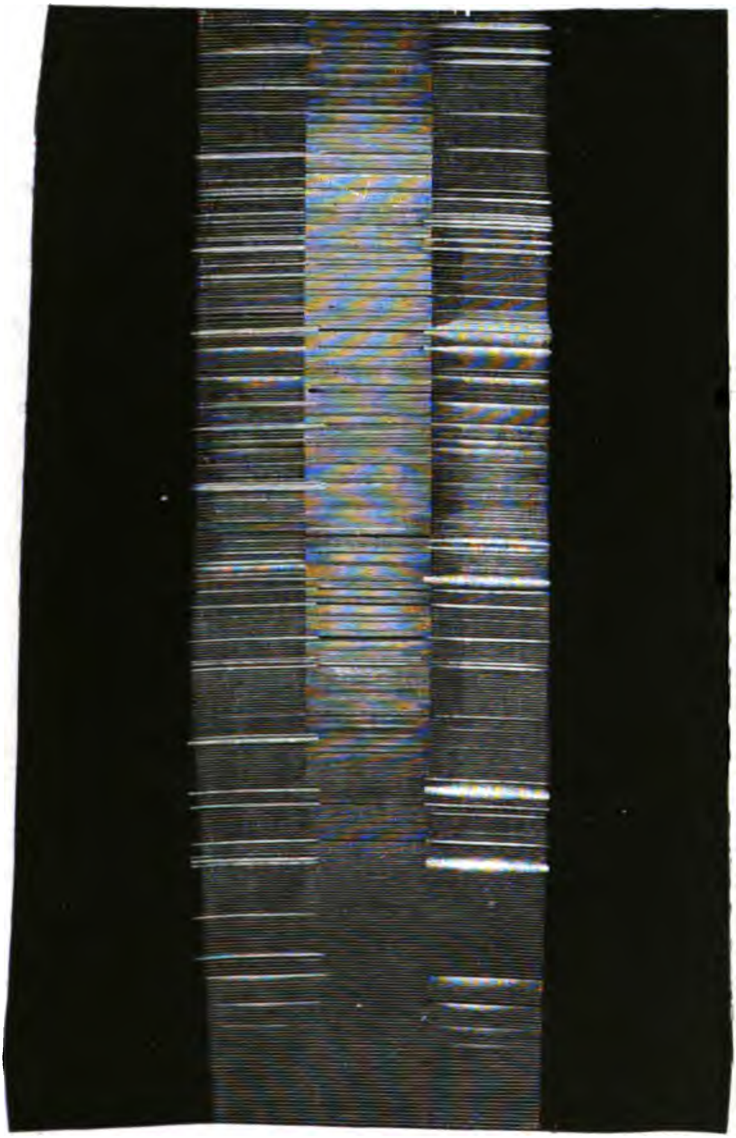


FIG. 136.—Photographed Spectra of Metals after Lockyer.

the Bessemer process. Cast steel is cast iron freed from its carbon, and in the Bessemer process, this is accomplished by forcing a blast of air through the melted iron while confined in a pear-shaped vessel, termed the converter, until the carbon is oxidized. The heat of the molten metal is so intense that the incandescent vapours of all the substances in combination with the iron are visible at the mouth of the convertor in the form of flame. If this is examined with the spectroscope, it will be found that the spectrum undergoes important changes as the process of heating the iron advances, and these changes afford a means of recognizing the moment when the process of oxidation is complete and when the blast must be discontinued. The recognition of this moment is of extreme importance, inasmuch as an error of less than a minute is sufficient to spoil a hundred tons of steel. And yet, before the application of the spectroscope, this responsible decision was practically left to the judgment of an experienced eye. The certain method offered by the spectroscope has led to its introduction in various forms, direct-vision and otherwise, in all the great foundries of Europe.

The spectrum of the incandescent gases is subject to brilliant changes during the successive steps of the process, and these changes follow with such regularity as to afford a certain indication of the actual state of the metal. The spectrum appears at first without lines, but no sooner do sparks begin to appear and the bright flames to escape from the mouth of the convertor, than the sodium line shines out brilliantly, and continues visible as long as the blast is applied. Next in succession appear the red lines of calcium and lithium, followed by a brilliant assemblage of green and pale blue lines, until when the maximum heat is attained, the brilliant spectrum of chloride of copper is exhibited. At this stage an experienced eye can sometimes

detect in addition a line in the violet. The characteristic lines, however, of the Bessemer spectrum are the band-like groups of lines in the blue and green. In the reverse order in which the lines made their appearance they gradually diminish in brightness, and successively vanish. After the disappearance of the blue lines there still remain some lines in the green, and it is at this stage that the spectrum must be unremittingly watched, for the only and unfailing indication of the complete oxidation of the carbon is a gradually heightened brilliancy of certain lines which remain in the spectrum after the process of oxidation is concluded. Variations in the description of iron ore exert a certain influence upon the appearance of the characteristic green lines. As this can only be ascertained by experience, some uncertainty may exist in the first operation, but this may easily be counteracted by a mechanical test. If a small quantity of the boiling metal be abstracted by an iron rod and plunged into cold water, its appearance upon fracture will reveal the amount of steel in the convertor.

PART THIRD.

SPECTRUM ANALYSIS IN ITS APPLICATION TO THE SUN.

SPECTRUM ANALYSIS
IN ITS APPLICATION TO THE SUN.

64. Coincidence of the dark Fraunhofer Lines with the bright Spectrum Lines of Terrestrial Elements. —Kirchhoff's Maps.

The coincidence observed by Fraunhofer of the two D-lines in the solar spectrum with the two bright lines discovered by Kirchhoff and Bunsen to be those of sodium induced Kirchhoff to put this coincidence to the most direct test by obtaining a tolerably bright solar spectrum, and then bringing a sodium flame in front of the slit.

"I saw," says Kirchhoff, "the dark lines D change into bright ones. The flame of a Bunsen lamp showed the sodium lines on the solar spectrum with an unexpected brilliancy. In order to find out how far the intensity of the solar spectrum might be increased without impairing the distinctness of the sodium lines, I allowed direct sunlight to fall upon the slit through the sodium flame, and saw to my astonishment the dark lines D standing out with extraordinary clearness. I replaced the light of the sun by a Drummond light, the spectrum of which, like that of every other incandescent solid or liquid body, contains no dark lines; when this light was allowed to pass through a flame in which salt was burning, dark lines

appeared in the spectrum in the position of the sodium lines. The same thing occurred when, instead of a cylinder of incandescent lime, a platinum wire was used, which, after being made to glow in a flame, was brought near its melting-point by an electric current."

From these observations Kirchhoff could no longer doubt that the dark lines D in the solar spectrum were due to the presence of sodium vapour in the sun, and that they must be produced in the sun by *reversion* (absorption).

After the existence of sodium had been thus suspected in the sun, Kirchhoff commenced the arduous undertaking of comparing the spectra of a variety of terrestrial substances with the solar spectrum, to determine whether any of the lines of these substances coincided with the Fraunhofer lines,—that is to say, if they appeared in the spectroscope in the same place, and were of similar breadth and intensity.

Kirchhoff allowed the light of the sun to fall directly on to the prisms through the *lower* half of the slit, while the *upper* half was covered by the small comparison prism. The rays from an artificial source of light placed at the side were so reflected by the prism into the instrument, that while the solar spectrum with the Fraunhofer lines was seen in the *upper* half of the field of view in the (inverting) telescope, the spectrum of the artificial light appeared below, and in immediate contact with it. Thus the position of the bright lines of this spectrum could be compared with great accuracy with that of the dark lines of the solar spectrum.

The artificial light employed was the spark from a powerful Ruhmkorff coil, with electrodes of the metals to be volatilized.

By the comparison of these spectra with the dark lines of the solar spectrum, Kirchhoff arrived at the surprising

discovery, that the bright lines due to the vapours of several metals were coincident with the same number of lines in the solar spectrum.*

The coincidence of the two sodium lines D is shown in Fig. 137; the upper part represents a portion of the solar spectrum with the two dark D-lines situated in the yellow; the lower part shows the bright lines given by sodium vapour. With a more powerful instrument, another fine line, corresponding to a bright line of nickel, appears between the two dark lines.

FIG. 137.

Coincidence of the Fraunhofer D-lines with the Lines of Sodium.

Two portions of the spectrum, the one situated in the yellow between 120 and 125 of Kirchhoff's scale, and the other in the green between 150 and 154, are represented in Fig. 138. The lower thirteen bright lines, designated Fe=Ferrum (iron), are lines in the spectrum of iron; they fall in exact accordance with an equal number of dark lines in the solar spectrum. The remaining twelve bright lines indicated by dots belong to the spectrum of calcium, and are coincident with as many dark lines in the solar spectrum.

In the portion of the spectrum published by Kirchhoff there are some sixty bright lines of iron, coincident with as many dark Fraunhofer lines, and since then the coincident lines of iron have been increased to above 460. The coincidence of so many bright lines cannot be the effect of chance.

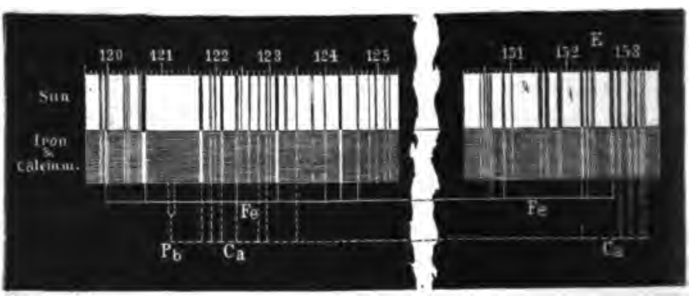
A glance at Fig. 139, in which the coincidence is shown of more than sixty of Kirchhoff's observed lines of iron with as many dark lines in various parts of the solar

* [It must be recollected that only some of the lines are coincident.]

spectrum between C and F, justifies the conclusion that those dark lines are to be ascribed to the absorptive effect of the vapour of iron present in the atmosphere of the sun. The chances that the coincidence of sixty lines is fortuitous, and not due to the presence of iron in the sun's atmosphere, according to the doctrine of probabilities, is 1 to 2^{60}, or 1 to 1,152,930,000,000,000,000.*

Kirchhoff's researches led him to the following conclusions with regard to the existence of certain elements in the sun:—

FIG. 138.



Coincidence of the Fraunhofer Lines with the Lines of Iron and Calcium.

Present.		Doubtful.	Not Present.	
Sodium	Nickel	Cobalt	Gold	Lead
Iron	Barium		Silver	Antimony
Calcium	Copper		Mercury	Arsenic
Magnesium	Zinc		Aluminium	Strontium
			Cadmium	Lithium
			Tin	Silicon

To these Lockyer has added manganese, titanium, and hydrogen, and confirmed the suspected presence of cobalt.

* [These probabilities are very much diminished, however, when it is found that not all the iron lines are found in the solar spectrum. Putting it in one way, it might be assumed that there was some substance in iron which was also in the sun.]

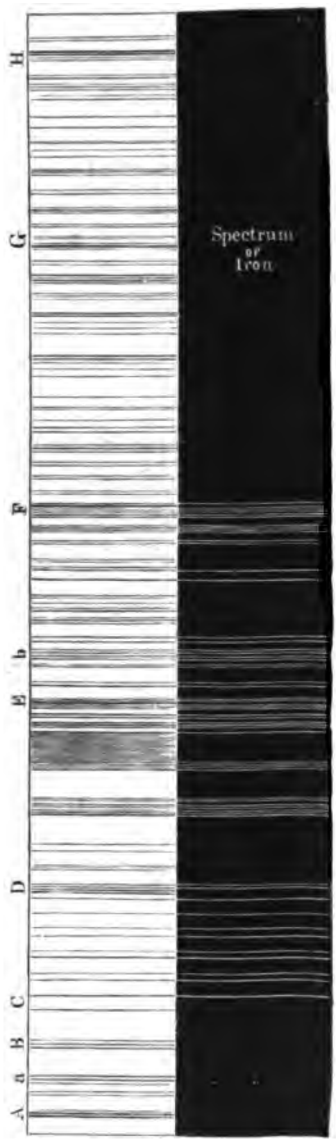


FIG. 139.—Coincidence of the Spectrum of Iron with sixty-five of the Fraunhofer Lines.

Later, by means of a special application of photography, Lockyer compared the spectra of most of the metals with the solar spectrum direct, and has published a series of tables which will be found in Appendix L.

The non-existence of any metal in the sun cannot, however, be considered proved till after a careful scrutiny of the ultra-violet parts of the spectrum, inasmuch as coincidences of lines might take place there although absent in the rest of the spectrum.

Of the non-metallic elements, oxygen, nitrogen, carbon,* or sulphur, there seems to be no certain trace discoverable in the sun, although Professor Henry Draper announced in the year 1876 that he had succeeded in recognising, by means of photography, the existence of oxygen and probably also of nitrogen, and that though oxygen exhibits bright lines or bands in the solar spectrum,

* [Lockyer has found carbon in the sun.]

it certainly produces no dark absorption lines.* To substantiate his assertion Draper published an absolutely untouched photograph of the solar spectrum, together with a comparison spectrum of air in which were some lines of iron and aluminium.

Draper accounts for the oxygen lines not having been before observed by the circumstance that on a luminous ground bright lines do not make so great an impression on the eye as dark ones. Draper's deductions, however, have not found general acceptance among spectroscopists. At the Greenwich observatory Mr. Christie has directed special attention to the subject. In the spectroscope attached to the great refractor a number of fine lines are visible which do not appear in either Ångström's or Kirchhoff's maps, nor in Draper's photograph, while the intenser absorption lines are comparatively narrow and sharply defined. The effect produced is that a space between two dark lines which in a spectroscope of less power appears as a bright line ceases to appear so, and seems to be only the background formed by the continuous spectrum. In a drawing representing the portion of the spectrum less refrangible than G, four such spaces included between the strongly marked lines 4314·4, 4316·3, 4318·1, and 4320·2 are to be noticed, which when not well defined or when seen with a low dispersive power would be taken for bright lines, and in fact the two inner lines were so regarded and identified by Draper as a double oxygen line. But each of these spaces, as seen at Greenwich, is ten times as wide as the dark lines, and absolutely uniform in colour, without any appearance of fading at the edges. Now it is difficult to explain the existence of bright lines which should remain of considerable width and well defined at the edges when the slit was narrowed. Usually, when a bright line is wider than the

* [This was the substance of Draper's claim.]

slit it fades away at the edges, but the spaces in question, or "bright lines," are completely uniform in tint. Christie was further unable to detect the slightest variation in tint in the whole portion from 4312 to 4322, under circumstances which showed two fine absorption lines in each of these spaces, no trace of which was visible in Draper's photograph. As already stated, the general opinion among spectroscopists inclines in favour of Christie's views; still the subject is not placed beyond doubt, and before it can be decided further investigations are requisite. This is all the more necessary as Draper* has come to the conclusion, from photographs of the dark lines of the solar spectrum compared with the bright lines of gases as photographed in the electric spark, that certain dark lines in the solar spectrum are in reality lines of oxygen.† Grating spectra were employed in these investigations. Between the wave-lengths 3864·50 and 4704·65 he found no less than sixty-five lines which, according to his measures, were either completely coincident or nearly so with the lines of oxygen.

65. Kirchhoff's Theory of the Physical Constitution of the Sun.

Kirchhoff's discoveries led him to a new conception of the physical constitution of the sun differing widely from the theories entertained by Wilson and Sir William Herschel in explanation of the solar spots. According to Kirchhoff the sun consists of a *solid* or *partially liquid* nucleus in the highest state of incandescence, which emits, like all incandescent solid or liquid bodies, every possible kind of light, and therefore would of itself give a *continuous* spectrum without dark lines. This incandescent central nucleus is

* [This is not Professor H. Draper, but his brother.]

† [Schuster has also arrived at the same conclusion from measurements of the oxygen spectrum and that of the sun.]

surrounded by an *atmosphere* of lower temperature, containing, in a state of vapour, many of the substances of which this body is composed. The rays of light therefore emitted by the nucleus must pass through this atmosphere before reaching the earth, and each vapour extinguishes from the white light those rays which it would itself emit in a glowing state. Now it is found, when the sun's light is analysed by a prism, that a multitude of rays are extinguished, and just those rays which would be emitted by the vapours of sodium, iron, calcium, magnesium, etc., were they self-luminous; consequently the vapours of these substances must exist in the solar atmosphere, and these metals must be present in the body of the sun.

Could the light from the sun's nucleus be set aside, and only that of the incandescent vapours of the sun's atmosphere be received through the slit of the spectroscope, a spectrum would be obtained composed of the spectra of these substances; that is to say, the same system as bright coloured lines which now appear as the dark Fraunhofer lines. The occurrence of a total solar eclipse affords an opportunity for applying such a test for Kirchhoff's theory, for as the sun's disc is then covered by the moon, and all light from the *body of the sun* is intercepted, no light can be received except from the solar atmosphere and the glowing vapours by which the nucleus is surrounded.

Kirchhoff's theory has received full confirmation from the observations of total solar eclipses. In that of December 22nd, 1870, Young observed that when the sun was covered by the disc of the moon, all the Fraunhofer lines were reversed and the field of view filled with bright lines. The same phenomenon was observed by Maclear and Pringle at Bekul in India during the eclipse of December 12th, 1871. On the approach of totality the bright lines increased in number and brilliancy with great rapidity, till for an instant

it appeared as if all the dark lines of the spectrum had turned to bright ones. The brilliancy of the lines then began to diminish, and so rapidly that it was impossible to follow the order in which they disappeared. The hydrogen lines, as well as D, *b*, and a few intermediate lines, remained visible for some time; upon their disappearance the field of view became dark. Upon the reappearance of the sun, Pringle also saw a great number of bright lines shine out from a continuous spectrum, which was visible up to the moment of the reappearance of the sun's limb. A somewhat similar observation was made by Respighi. In the total solar eclipse of April 16th, 1874, a reversal of all the dark lines was observed by Stone, both immediately before and after totality, and the same was noticed in the eclipse of July 29th, 1878. The thickness of the reversing stratum appears from these observations to be comparatively very small: according to Pulsiver's estimation it cannot much exceed 500 miles.

As early as 1869 Secchi, by a method of observation of extreme delicacy, had proved the existence of this reversing stratum. The image of the sun, formed by his nine-inch equatorial, was enlarged by the object-glass of an excellent microscope, and examined through a spectroscope, consisting of three prisms of high dispersive power, which was further increased by the addition of a direct-vision system of prisms. After the slit had been placed tangentially to the sun's edge, the clock motion was so arranged that the sun's disc should gradually approach the field of view of the telescope. The following results were obtained:—1. At a short distance from the sun's edge the light is so intense that its spectrum exhibits even the finest and darkest lines of the solar spectrum. 2. At a still shorter distance from the sun's edge the bright lines of the prominences and of the chromosphere appear. 3. At a still nearer approach these bright lines become fainter, and there comes a moment when all the dark lines except the

most prominent, such as D and *b*, disappear. 4. This last stratum yielding a continuous spectrum is very thin, for almost immediately after the appearance of the continuous spectrum, the complete solar spectrum, with all its dark lines, comes into view, and announces the entrance of the actual limb of the sun or photosphere. The phenomenon described under No. 3 is due to the reversing stratum, and its excessive thinness is no doubt the explanation that in the eclipses of 1868 and 1869 the reversal of all the lines was not remarked. The reversal would doubtless occur during totality, but escaped the notice of the observers, partly from inexperience in this new field of observation, and partly from the instruments not being specially adapted to the exhibition of the phenomenon. Kirchhoff's theory has therefore been triumphantly justified by observation, with the unimportant difference that the reversal of the lines does not occur in the far-reaching solar atmosphere, but in a lower stratum* lying immediately above the photosphere of which it possibly forms a part.

66. The Atmospheric Lines in the Solar Spectrum as observed by Brewster and Gladstone.

The Italian physicist Zantedeschi was the first to remark that the dark lines in the solar spectrum are not all invariable, and that the changes occurring in number, position, intensity, and breadth, in some of them are due to the varying condition of the earth's atmosphere. In 1856 Crookes called attention to the fact, upon which he placed some importance, that the atmosphere absorbed a great part

* [Observations by Lockyer, in the eclipse of 1882, lead him to suspect that the reversing vapours, instead of being confined to one layer, have their locus at what he calls different heat levels. By this he accounts for the different lengths of the bright lines seen at the commencement and end of total eclipses.]

of the most refrangible rays, and that on this account the violet end of the spectrum was the most extended when the sun was nearest the zenith. This subject has since occupied the attention of Brewster and Gladstone, Piazzi Smyth, Secchi, and pre-eminently the French physicist Janssen, but their investigations have not as yet led to any conclusive result.

Gladstone prepared drawings of the solar spectrum, which were laid before the British Association in 1858, and in which the dark lines which appeared as the sun approached the horizon were carefully registered. The cause of these lines was unknown, although it was suggested that an explanation might be found by observing some terrestrial source of light from a great distance. Gladstone observed the light at Beachy Head from a distance of twenty-seven miles, but without noticing the appearance of any new lines. Subsequently he again took up the subject with Brewster. They found that new dark lines and bands made their appearance in the solar spectrum when the sun approached the horizon, and that certain dark bands were more strongly marked in the morning and evening than at noon, when the sun is high in the heavens. As the sun when near the horizon transmits its rays through a stratum of air nearly fifteen times as thick as when at a high altitude, the idea was suggested that the atmosphere, though colourless, might obstruct the rays as vapours do, and exercise an absorptive influence upon the light proportionally to the thickness and density of the stratum through which the solar rays have to pass.

The solar spectrum published by Brewster and Gladstone in 1860, nearly five feet in length, contains more than 2,000 dark lines or bands. The violet end extends as far as in Fraunhofer's map, while in the direction of the red it is of considerably greater length. The Fraunhofer lines retain

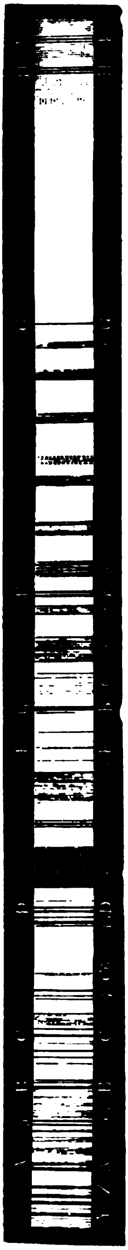


Fig. 140.—The Brewster-Gladstone Solar Spectrum, with the Atmospheric Lines.

their original designations, while the lines and bands interspersed between them, and clearly separable one from the other, are marked by figures after the letters A, *a*, B, C, etc. Thus between A and *a* there lie three bands, marked A_1, A_2, A_3; between *a* and B there are eight lines or bands, marked a_1, a_2, . . . a_8. There are seven lines between B and C, sixteen between C and D, twenty-nine between D and E, ten between E and *b*, thirty between *b* and F, fifty between F and G, fifty-three between G and H, four between H and *k*, and ten between *k* and I, each line marked by a number, beginning always with 1. Besides these prominent lines, there are many very fine lines interspersed among them which are not enumerated. Those lines and bands which are pre-eminently influenced by atmospheric conditions, being more or less prominent according to the altitude of the sun, are designated by the letters of the Greek alphabet.

The solar spectrum given in Fig. 140 is taken from a reduced drawing by Brewster, and represents, in conjunction with the Fraunhofer lines A . . . . H, all the variable lines and bands of any importance marked by the Greek letters; the numbers are omitted. The drawing shows the spectrum as it appears when the sun is near the horizon; all the lines and bands marked by the Greek letters disappear from the spectrum, or become more or less pale, as the sun attains a meridian altitude. These

bands were named by Brewster and Gladstone *atmospheric*, to indicate that they were formed by the absorptive power of the earth's atmosphere; but to what component of the air this selective absorption was due was not ascertained.

In the least refrangible portion of the spectrum two intensely dark bands appear at sunrise in front of A, bordered by the fine lines Y, Z. A increases much in breadth, and preserves this width even when the sun has a considerable altitude. When A is observed at noon, it appears as a double line, or like two dark spaces separated by a narrow band of light; when the sun is setting, this bright stripe disappears, and the line is seen as *one* band of uniform width and intensity.* The group *a* increases in intensity towards sunset, but the individual lines do not blend into a band.† The strongest absorption takes place close to B. C and most of the lines between C and C_6 become darker, and C_6 (in the orange) is especially remarkable, as it deepens in intensity while the sun is yet high in the heavens. In England this line is visible during the whole day in winter, but not in summer; at sunrise and sunset it is one of the darkest and best-defined lines in the spectrum. C_{15} increases towards evening to a black band, and the double line D becomes very prominent. Behind D_2 a band, marked δ, begins, which is peculiarly characteristic of light that has travelled through a thick stratum of air. Even in a small spectroscope, this band may be readily seen at any hour in the diffused light of a dull day, but it is particularly dark and

* [Whether at noon or sunset, A always preserves the same appearance, and there is doubt if it is an atmospheric line. Eggeroff has stated it is an oxygen line, but this needs confirmation.]

† [There is often a mistake made in comparing lines at sunset and at midday. At sunset the whole light is dimmed, and lines appear blacker from this cause alone. It is a good plan to examine such lines through a darkly-tinted image at midday, and compare their appearance then with their appearance at sunset.]

well defined during heavy rain or a thunderstorm, and at sunset it becomes almost black. The same is noticed in the bands ϵ and ζ, as also in the line η, which is very distinct at evening, and from its proximity to E, which remains unaffected by the atmosphere, may easily be mistaken for it. On the further side of *b* are several other remarkable atmospheric bands, particularly ι and χ. F loses its sharpness at sunset, and seven bands from λ to ς become visible between F and G. At G the only change is a loss of brightness towards evening, but a still greater amount of absorption takes place beyond, in the violet rays.

The western sky immediately after sunset affords the best opportunity for observing these dark atmospheric lines, especially the bands δ and ζ in the bright parts of the spectrum. If the sky is red, the lines C, C_6, D, δ usually appear as four very dark bands, but when the sky is yellow they are much less distinctly marked.

67. The Telluric Lines in the Solar Spectrum and the Spectrum of Aqueous Vapour, as observed by Janssen.

In 1864 the investigations of Brewster and Gladstone were pursued by the French physicist Janssen, for the purpose of discovering to what substances in the atmosphere the selective absorption of the solar spectrum was due. With an instrument of his own construction, composed of five prisms, he succeeded in resolving the dark bands noticed by the English observers into very fine lines, and in ascertaining that their intensity was perpetually varying. He found them to be darkest at sunrise and sunset, and less intense in the middle of the day, but they were never entirely absent from the spectrum, a periodicity of change which at once proves their atmospheric origin. To procure still more de-

cisive evidence on this point, Janssen resolved to pursue his observations on the solar spectrum from the top of a high mountain, whence the absorptive influence of the lower and denser stratum of the atmosphere would be excluded, and the effects of absorption would be manifested in a modified form.

For this purpose, in the year 1864 Janssen remained for a week at the summit of the Faulhorn, at a height of 8,800 feet above the sea, and convinced himself that the variable dark lines in the solar spectrum were undoubtedly much fainter there than in the plain. But in order to discover the origin of this absorption, and to obtain proof that these lines were alone due to the earth's atmosphere, he selected for examination artificial light, since the light of the sun before reaching the earth has to travel for millions of miles through foreign media.

In October 1864 he caused a large pile of pine wood to be set on fire at Geneva, at a distance of thirteen miles from his place of observation, and observed the flame in the spectroscope; when viewed near, the fire gave a continuous spectrum without dark lines, but at the full distance some of the dark lines appeared which Brewster had observed in the spectrum of the setting sun.

It now remained for Janssen to determine whether this atmospheric absorption was to be ascribed to the air or to the aqueous vapour contained in the air, an investigation beset with unusual difficulties, but which was at last accomplished when in 1866 the Gas Company of Paris placed a piece of apparatus at his disposal.

An iron cylinder 118 feet long, after being exhausted of air by forcing steam through it under a pressure of seven atmospheres, was filled with steam and closed at both ends by pieces of strong plate-glass. The cylinder was surrounded with sawdust to prevent radiation, and additional

Fig. 141.—Janssen's Solar Spectrum on the Meridian and at the Horizon (Telluric Lines).

precautions were adopted to preserve the steam from condensation, and thus maintain its transparency. A very bright flame (produced by sixteen united gas-burners) was examined by the spectroscope through the length of the cylinder, so that the rays in reaching the instrument had to pass through a stratum of aqueous vapour 118 feet thick. The spectrum of the light in the air was entirely free from absorption lines; but seen through the cylinder of steam, groups of dark lines appeared between the extreme red and the line D, similar to those seen in the spectrum of the setting sun. By this means not only was the proof furnished that a large number of the variable lines in the solar spectrum are due to the presence of aqueous vapour in the earth's atmosphere, but also a method secured for detecting the presence of aqueous vapour in the heavenly bodies.

Fig. 141 represents the solar spectrum between the lines C and D as drawn by Janssen; the upper half is the spectrum

of the sun in the meridian, the lower half that of the sun at the horizon. Those lines which present the same appearance in both halves belong exclusively to the sun, while those which are darker in the lower than in the upper half are *telluric lines*.

It has been further shown by Janssen that almost all telluric lines are produced by the *aqueous vapour* of the earth's atmosphere; that an absorptive influence is also exerted by this vapour on the invisible portion of the solar spectrum beyond the red (that is to say, in the heat spectrum), where it produces absorption lines; and, finally, that it affects the whole of the violet portion of the spectrum in a manner more nearly uniform than selective.

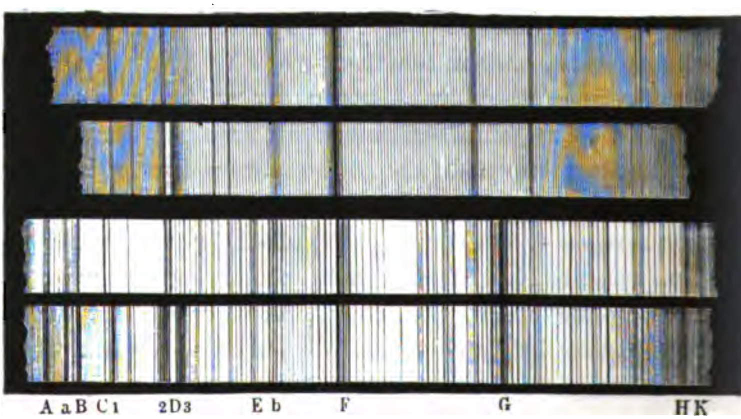
The absorption spectrum of aqueous vapour consists therefore of all the lines introduced into the continuous spectrum by the aqueous vapour of the earth's atmosphere; it is an absorption spectrum which may be easily constructed for the portion between C and D by leaving out all those lines from the lower part of Fig. 141 which present a similar appearance to those in the upper half. It has been proved that the groups marked Cβ and D arise from the aqueous vapour in the atmosphere; the *telluric* character of the central group Cγ has been also established by Janssen, but it remains uncertain whether they are likewise to be attributed to aqueous vapour.

The investigations of Janssen were not confined to the portion of the solar spectrum included between C and D; he continued the spectrum in another map, reaching from below the line B to beyond D; in this spectrum are included the three groups marked by Brewster α, β, γ, δ (Fig. 141). He also extended his observations to the light of the moon and stars, with the view of ascertaining if the stellar light, which differs from that of the sun, is subject to similar changes in its passage through the earth's atmosphere.

With this object he applied a small direct-vision spectroscope to a powerful astronomical telescope, and examined the spectrum of Sirius as the star rose above the horizon. In its very bright spectrum were several dark bands occupying precisely the same position as the dark bands that appear in the solar spectrum at sunrise and sunset. As Sirius gained in altitude, the intensity of these telluric bands diminished until as the star passed the meridian they disappeared.

Fig. 142 gives the spectrum of the sun (II.), and that of

FIG. 142.



Spectrum of Sirius and the Solar Spectrum on the Meridian and at the Horizon.

Sirius (I.), as seen in the small spectroscope when observed in the meridian and at the horizon. The dark bands marked 1, 2, 3 are evidently telluric absorption bands common to both the sun and Sirius when near the horizon.

Secchi also observed for many years the telluric lines of the solar spectrum. From the first he expressed an opinion that these dark lines which vary with the place of the sun, the position of the observer, and the amount of humidity in the air, were to be ascribed to the absorptive action of the aqueous vapour in the atmosphere. The influence of the

weather was apparent, for while some of these lines were invisible in clear weather with a north wind, they were strongly marked on dull days with the wind in the south. Secchi also observed and measured the dark absorption lines during rainy weather in the spectrum of a flame distant 2,000 metres ($1\frac{1}{4}$ mile), as well as in that of large fires kindled on the mountains.

Ångström of Upsala in the year 1864 instituted careful investigations of the telluric lines in the solar spectrum, and introduced these lines into his maps according to the wave-lengths of the colours they absorbed. In Fig. 143 a map of these lines is given on a reduced scale; the lines and bands are all atmospheric with the exception of the Fraunhofer lines C, D, E, *b*, F. Ångström thus describes the order of the phenomena produced by the absorptive power of the atmosphere as the sun approaches the horizon. See Plate XI.

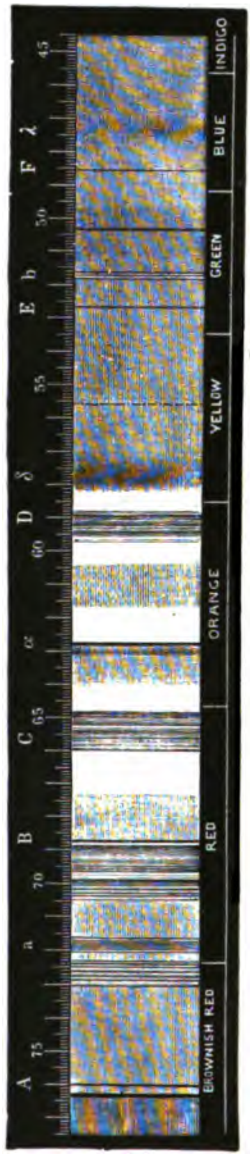


FIG. 143.—The Telluric Lines in the Solar Spectrum after Ångström.

The violet portion of the spectrum disappears as far as G; the absorption then keeps advancing towards the red, and intensifies the dark bands near F and D. Simultaneously the lines A, B, and *a*, which are always visible in the red, become much darker,

and the lines of aqueous vapour both at C and D continually augment. At last the only parts remaining bright lie between B and *a*, between *a* and δ, and in the greater portion of the greenish-yellow in the vicinity and to the right of δ, while the portion between B and δ is more or less shaded by dark bands. The part of the spectrum least affected by the telluric absorption lies between D and δ.

Ångström concurs with Brewster that nearly all the changes of colour in the red glow of sunrise and sunset can be explained by the phenomena of atmospheric absorption. He is of opinion that the bands A, B, *a*, and δ are not produced by the aqueous vapour of the atmosphere, as they are nearly constant, and are unaffected by changes of temperature. He supposed that the lines were due to carbonic acid; but when Huggins compared the spectrum of the carbonic acid of free air with that of the atmosphere no difference was perceptible. An addition of carbonic acid brought out a few new lines, which were not, however, coincident with those of carbon.

In the balloon ascent undertaken by Sivel and Crocé-Spinelli on the 22nd March, 1874, it was remarked that at a height of 3½ miles, the dark band δ to the right of D was no longer visible; and that, at a height of 4½ miles, the band to the left of D had also disappeared. These observations, however, are at present too isolated to afford a foundation for any definite conclusion.

[One of the most beautiful researches on the subject of telluric lines has been made by Cornu. It will be seen in a subsequent chapter that the position of a line slightly varies from its normal position according as the vapour through which the radiation comes is approaching or receding from the observer. Now we know that the sun rotates, and that consequently one limb, with its vaporous envelope, is approaching us, whilst the other limb recedes

from us. If then the centre of the sun's disc be observed where there is no motion towards the observer, the lines due to the incandescent vapour will be in their normal position, whereas if the light from the east or west limb be observed, these lines will be slightly displaced. In both cases the position of the lines due to atmospheric absorption would be the same. If then by an artifice the images of the east and west limbs of the sun, alternately and fairly rapidly, be thrown on the slit, the solar lines will be seen to recede from and advance towards the air lines. It is thus that Cornu has studied the question and mapped a large portion of the spectrum.]

68. The Telluric Lines in the Solar Spectrum as a Means of Prognosticating the Weather.

The telluric lines in the solar spectrum being caused by the moisture of the atmosphere, and their width and intensity being governed by the amount of this aqueous vapour, it would seem to be possible to estimate the amount of moisture by the intensity of the lines. The greater the amount of vapour in the air the greater is the tendency, under similar conditions, to produce rain, which is merely the condensation of the aqueous vapour of the atmosphere. Meteorology, it is true, possesses in the psychrometer an instrument to measure the amount of moisture in the air, but its action is very imperfect, and it can only take cognizance of the condition of the air in its immediate neighbourhood. As the aqueous vapour of the atmosphere is formed at great heights, especially in those strata where rain and snow are formed, the psychrometer is quite unable to give any information as to the condition of the air in those regions. This is not the case with the spectroscope. In whatever direction it is turned, it takes account

of the total absorption effected in a straight line from the observer to the furthest boundary of the atmosphere. Professor Piazzi Smyth seems to have been the first to employ the spectroscope with reference to the accompanying meteorological conditions, and his observations date from 1874. In an article in *Nature*, vol. xii., p. 232, he describes his first study in the matter.

His attention having been awakened to the subject, Professor Piazzi Smyth pursued his investigations further. For several months, when observing with the spectroscope, he recorded the amount of moisture in the air by the psychrometer, and although, as we have pointed out, the quantity of vapour in the higher regions of the air cannot be thus registered, still there was a very tolerable agreement in the results furnished by the two instruments. Under otherwise similar circumstances, the lines of aqueous vapour increased in blackness in proportion to the amount of humidity in the air. It is obvious that in examining the state of the atmosphere, and for the comparison of the telluric lines, the spectroscope should always be directed at the same angle above the horizon, and the observations are of most value when this angle is small. Under these conditions Piazzi Smyth secured the following results:—In frosty weather, when the moisture of the air was at its minimum, the normal spectrum of the dry gases of the atmosphere was obtained. It consists principally of the line B, of the line *a* between C and D, and of a very striking band near D towards the green. This band is remarkable not only from appearing as a dark shadow in the brightest part of the spectrum, but also because it is chiefly developed at a low altitude, and on this account is designated by Smyth as the "low sun band." In summer, with a high temperature, when the atmospheric moisture is considerable, there was observed, in addition to the dry gas-spectrum mentioned

above, a strong aqueous vapour line, immediately following C, also a much stronger and double line, or rather two bands of lines, just before D. In practical meteorology, this group of lines in the spectrum of aqueous vapour is the only one that need be studied.

When familiarity has been gained with the normal appearance of this band at a given temperature, and its intensity is observed to become twice as great without any great alteration in temperature, it may be safely regarded as a "rain-band." For this excess of blackness infallibly declares that the moisture of the atmosphere has become too great to be long further suspended, and must soon fall in the form of rain. Fig. 144 exhibits the various appearances of the rain-band as drawn by Piazzi Smyth, both in direct sunlight and in the diffused light of day. The former cannot often be observed; its appearance is shown in No. IV. The shaded surfaces indicate the diminution of light in those parts of the spectrum. It will be noticed that all the lines are faint with the exception of A. This spectrum is seen on a summer day at noon, when the air is dry. No. V. is the direct solar spectrum at sunset, or when the sun approaches the horizon on a dry, cold winter's day. It differs obviously from No. IV., especially in the increase of darkness in front of B, and in the addition of a band at *a*. No. VI. gives the direct rain-band spectrum, as seen on warm damp summer days, when the sun is low, or on the approach of a thunder-storm. The most striking feature is the intense dark band *a*, and next the bands in front of D, as well as the dark shadows δ in the yellow-green. The increase in the breadth and intensity of γ is extremely characteristic, as also the dark line near C, and the broad band at *a*. As we have already observed, when there is great dampness in the air, and rain is imminent, it is seldom that the direct solar spec-

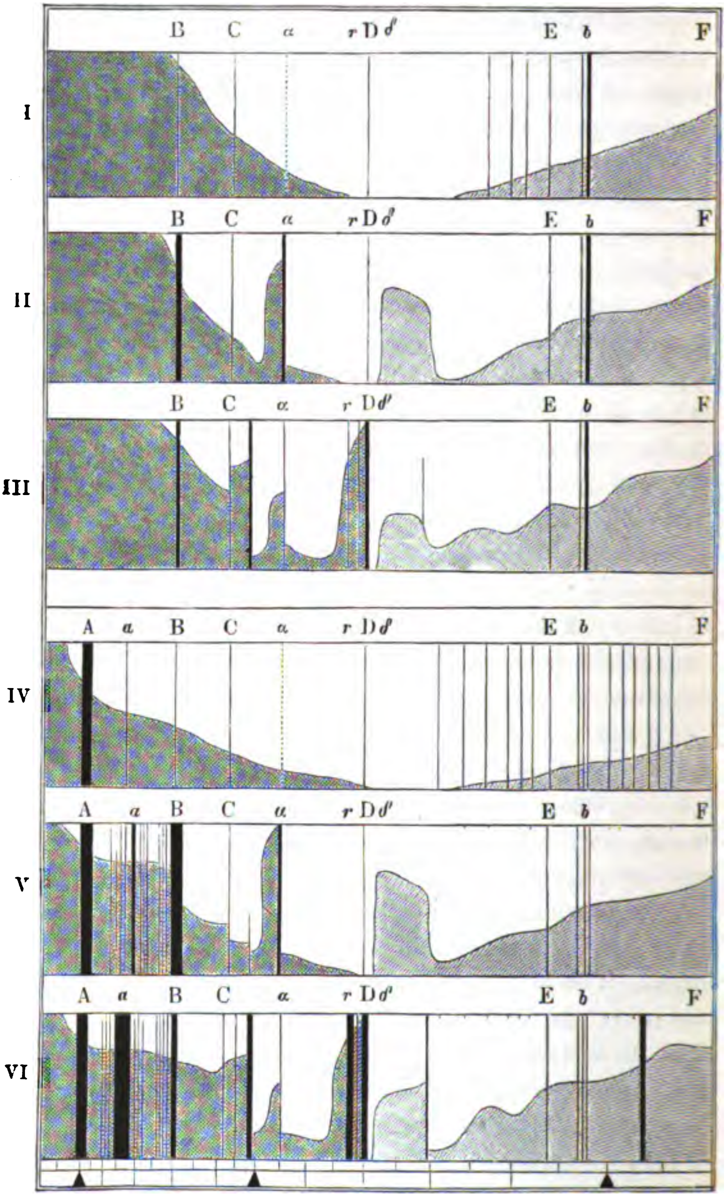


FIG. 144.—The Rain bands in the Solar Spectrum after Piazzi Smyth.

trum can be obtained, and the observer must therefore be contented with the scattered light reflected from the sky. Even thus the rain lines are very marked, perhaps even more intense, but the portion of the spectrum to the left of B is no longer visible. Nos. I., II., III. are good examples of such, as given by Piazzi Smyth, No. III. being the most important.

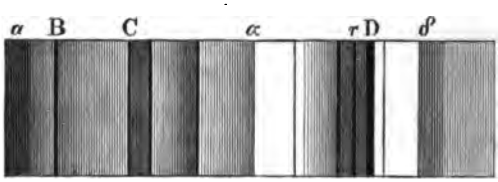
The author of this work has been in the habit for some years of regularly observing, in the service of meteorology, the aqueous lines, employing for this purpose a direct-vision spectroscope of three prisms, by Messrs. Reinfelder and Hertel of Munich. In dry weather, with a suitable adjustment of the slit, the instrument shows the D-line distinctly double. For observations of this nature such an instrument can be safely recommended, for after comparison with many others it was still found to be the most suited for the purpose.

From the observations hitherto made it would appear that upon a strong development of the aqueous vapour lines, rain generally follows within from three to twelve hours. In winter, however, the lines do not come out so strongly as in summer, when they are almost an unfailing indication of rain. This may happen, too, when at the time of observation the sky is cloudless. It may be remarked here that these observations are by no means so simple as appears from Piazzi Smyth's representations, inasmuch as it requires great practice to become so familiar with the normal appearance of the spectrum in the instrument employed as to detect any variation that may take place. The intensity and definition of the lines can best be registered by gradations, five of which will be found sufficient; so that if the line B, which is usually the strongest and darkest, be registered by five, a line only just visible will be designated by one. In this way numerous observations may be collected, and afterwards compared and arranged according to the accompanying atmo-

spheric circumstances, and a mean value obtained. Supported by such investigations, the spectroscope may do good service in the prognostication of the weather, at all events better than any hygrometer. In Fig. 145 that portion of the spectrum is given in which the rain-bands chiefly occur; it represents the spectrum as seen in summer before rain, by the use of the instrument just described.

[The subject is not yet fully worked out, however. There are *lines* due to aqueous vapour, but there seem to be also *bands* due to water in a state approaching to that of a liquid. Abney and Festing found, after a year's observation, that the amount of water in the air could be perfectly prognosticated by the appearance of the photographed solar spectrum in the red and infra-red regions. The bands which appear in the absorption spectrum of water of different thicknesses when a continuous spectrum was transmitted through a layer of it coincided with the bands of absorption in the solar spectrum when different degrees of moisture were present in the atmosphere. The spectrum of a vapour is essentially a line spectrum, whereas that of a liquid is a banded spectrum; hence the presence of these bands indicated liquid water, whilst the line spectrum showed the presence of aqueous vapour. There is a band below *a* which always increases in intensity when rain is about to fall, showing that the vapour is being condensed into a liquid.]

FIG. 145.



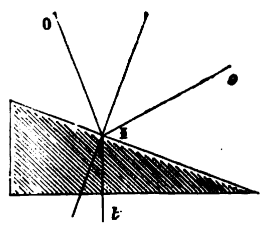
Marked Exhibition of Lines in the Rain-bands in the Solar Spectrum (Klein).

69. Telescopic Appearance of the Solar Surface.

The sun is to us the most important of all the heavenly bodies, and must therefore always form one of the chief objects of astronomical research. It is, however, a research fraught with peculiar difficulties, owing to the enormous amount of light and heat which the sun* emits.

In observing the sun, it is usual to place a dark-coloured glass, introduced between the eye-piece and the eye, and so to reduce the light to a moderate brilliancy. This plan suffices to show the principal phenomena on the surface of the sun; but if careful investigation is to be made with a large telescope, the dark glass must be replaced by a solar eye-piece. This consists of a right-angled prism of glass (Fig. 146), from the hypotenuse surface of which the incident ray O I is sent into the eye-piece in the direction of I *o*. This ray is much enfeebled in consequence of a considerable portion of the light being lost by its falling on the inner surface of the prism in the direction I *t*. The prism is confined in a metal case (Fig. 147), open at one side to avoid extreme heating. The diminution of light by this reflection being still insufficient, a lightly-tinted glass is also requisite. An inconvenience attending this form of eye-piece is that it rapidly becomes heated, so that when applied to a telescope of six or more inches aperture, and the sun observed at a high altitude, observations can only be carried on for a few minutes at a time;

Fig. 146.



Representation by Projection of the Rays of Light.

* [We must not complain of an abundance of light; it is where there is but a feeble light, as in stellar light, that we encounter the greatest difficulties.]

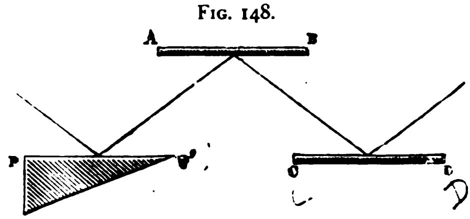
the image, too, is not well defined with a high power. A preferable arrangement is the polarising eye-piece, such as was employed by Secchi. The light falls at an angle of 36° upon the prism P P′ (Fig. 148), by which it is polarized, and next falls at the same angle of 36° upon a mirror of black glass A, B, placed parallel to the prism, whence it

FIG. 147.

Eye-piece Tube of the Solar Eye-piece.

is finally reflected at the same angle on to a second mirror, C D. While the prism and first mirror are permanently connected with one another, the mirror C D, mounted in a tube, revolves round the first reflected ray, and may be placed at any required azimuth with regard to the ray. If the reflecting surface of the second prism C D is placed

FIG. 148.



Path of the Rays in the Polarising Solar Eye-piece.

perpendicularly to the reflecting surface of the first prism A B, the sunlight will be so reduced that the eye can receive it without inconvenience, even when the sun is at its highest. The light does not absolutely disappear, nor is it desirable that it should. Fig. 149 shows the eye-piece one-fourth of the natural size.

If projected on to a screen, the sun's image may be

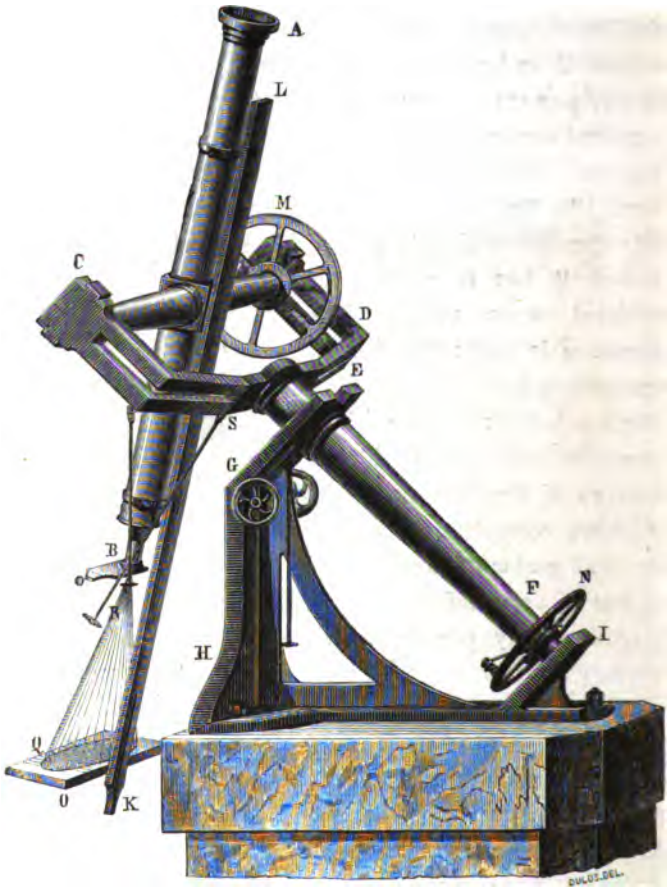
viewed by the unassisted eye. An arrangement for this purpose is shown in Fig. 150. A B is the telescope, to which a rod, L K, is attached, supporting at its lower end the board Q O. This board must be placed perpendicularly to the optical axis of the telescope, and at such a distance from the eye-piece B as to ensure a sharp image. The phenomena generally present are spots, some lighter, some darker than the general surface. The former are called *faculæ*, the latter sun-spots. With a sufficiently powerful telescope it will be noticed that the background of the solar surface is by no means even or uniformly bright, but that it has a mottled or granulated appearance. This *granulation* is not so well seen by projection as by direct vision through a solar eye-piece. The appearance is described by Secchi as if the surface of the sun were completely covered with small grains of nearly equal size, but of very different forms, the oval mainly predominating. The very narrow space between the grains forms a network, dark, but not quite black. In Fig. 151 we have endeavoured to give the general character of this remarkable conformation, but it would be vain to attempt a faithful representation of its details, as it is scarcely possible to give any description of this structure. The nearest resemblance is perhaps to be found in dried milk as it appears through the microscope when the globules have lost their accustomed form. When the sky is favourable the usual appearance with a low power resembles that given in Figs. 151 and 152, namely, that of small white specks thickly scattered over a very fine dark net. With the

FIG. 149.

Polarising Apparatus in the Solar Eye-piece.

smallest tremor or disturbance of the air, the image subsides into a surface of uniform smoothness. Sometimes the grains

FIG. 150.



Telescope for Solar Observations Fitted with Apparatus for Projecting the Image on a Screen.

congregate into groups forming luminous patches. On account of the elongated form, they have been compared to rice grains.

as they are not visible in the ordinary solar spectrum; the same observation was made with regard to the calcium lines.

In October, 1877, a spot was observed at Greenwich in which the changes in the lines of the spectrum were very remarkable. A table of them is given below:—

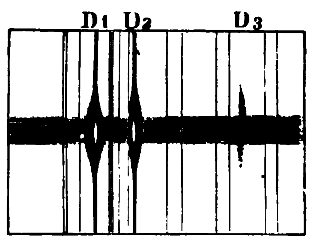
Element.	Number of Lines Observed.	Character of Change.
Calcium	12	Very much darker and about doubled in breadth.
Sodium	2	Very much darker. The two D-lines almost meet over the nucleus.
Titanium	11	Very much darker and about doubled in breadth.
Iron	30	Slightly broader, by about one-tenth, and decidedly darker, perhaps by one-half.
Barium	4	About twice as dark and twice as broad.
Magnesium	4	Much broader and darker.
Nickel	6	Broader by one-half, slightly darker.
Chromium	3	Somewhat darker, and broader by about one-tenth.
Hydrogen	3	Much fainter and less distinct. F-line reversed in the neighbourhood of the spot, due north of the centre on November 5th.
Coronal line	1	Much fainter over the spot.
D_3	1	Not seen either bright or dark, in spot or bridge.
Telluric bands	1	Band α broader and darker.

Besides the increase in breadth of the lines, displacements to the red or blue were noted, especially in the F and D-lines. On the 31st of October the F-line was twisted; the portion over the following half of the spot being displaced to the red, and the other half towards the blue. On the darkest part of the spot the D-lines were expanded towards the red as much as half the space between D_1 and D_2, while on the other side they were sharply defined, and not perceptibly displaced. Owing to cloudy weather, the spot was not seen before the 30th of October, when it was already well advanced upon the disc. Photographs were taken on 30th and 31st of October, and on 1st, 2nd, 3rd, 4th, and 5th of November, during which period it experienced but slight change. It was noticed that a group of small spots, closely

the bright lines of which overpower the dark lines of the spot, and cause them to be reversed.

Lockyer, while observing a spot on the 20th of February, 1869, noticed that the *magnesium* as well as the *barium* lines were increased in breadth, and he concurs with Secchi in the opinion that this widening of the Fraunhofer lines in the spectrum of a spot arises from the absorptive influence of the substances forming the spot, and that the spots are *deep recesses* in the surface of the solar body, *filled* with concentrated masses of the vapours of iron, calcium, barium, magnesium, sodium, and hydrogen, the spectrum lines of which increase in breadth and intensity, and *over* which *floats* the lighter hydrogen gas.

FIG. 162.



Reversal of the D-lines after Young.

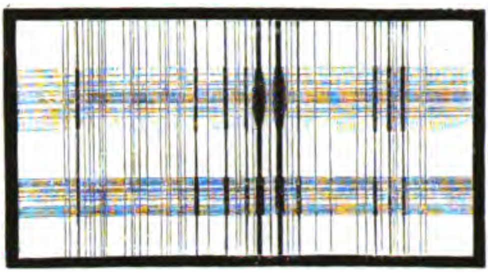
Professor C. A. Young, of Princeton, New Jersey (America), found, when observing a large group of spots on the 9th of April, 1870, that the hydrogen lines C and F were reversed in the nucleus,—appearing bright. C was very bright, F much fainter; the remaining hydrogen lines, Hγ (2796 Kirchhoff) and Hδ or *h* (3365·5 K.), were not reversed, but appeared as somewhat finer lines. He remarked also that many dark lines had become wider and darker, while others remained unchanged, among which were *a*, B, E, 1472 (K.), the lines *b*, 1691 (K.), and G. The two sodium lines D_1 and D_2, as well as 850 (iron), were evidently widened, but not to any considerable extent.

The lines most affected by the increased absorption in the substance of the spot were as follows: 864 (Ca.), 877 (Fe. ?), 885 (Ca.), 895 (Ca.), 1580 (Ti.), 1589 (Ti.), 1627 (Ca.), and 1629 (Ti.). The lines of titanium identified by Ångströms map were very prominent, and this was the more remarkable

vapours become much expanded. The D-lines especially increase in breadth, and as they assume a nebulous appearance lose their sharp edges, as shown in Fig. 161.

When the slit of the spectroscope is directed from the penumbra on to the nucleus, the metallic lines increase successively in breadth. When the slit includes both penumbra and nucleus, the lines are broadest over the nucleus, they become narrower over the penumbra, and vanish in a point. From this it may be deduced that the absorptive stratum, causing the expansion of the lines, increases either in depth or density as it approaches the centre of the nucleus.

FIG. 161.



Widening of the D-lines in the Spectrum of a Solar Spot.

Besides these characteristic changes exhibited in the lines, Secchi has remarked relative changes in the brightness of the various parts of the spectrum, especially in the red, yellow, and green. Dark bands are formed, for instance, between B and C, and in the neighbourhood of D. Another remarkable phenomenon is the occasional reversal of the two sodium lines, D_1 and D_2, in the spectrum of the nucleus; a similar observation was made by Young on the 22nd of September, 1870, a drawing of which is given in Fig. 162. Other lines are frequently reversed, namely, the lines C, F, D_3, $H\gamma$ (2796 K.), b_3, b_1, b_2, b_4; 1474 K., etc. Secchi explains the phenomenon by the presence of intensely bright prominences,

green between b and F, remarkable from being almost reversed. Stripe No. 1 is the spectrum of the bridge, in which the bright lines of hydrogen project into the spectrum of the nucleus. Stripe No. 3 is that of the penumbra, in which, on account of partial reversion, the dark lines of hydrogen are wanting.

Changes in the solar spectrum of so extraordinary a nature cannot be explained merely by a general diminution of the light; the expansion of certain lines points to the conclusion that the vapours of certain metals present in the interior of the spot exert a powerful selective absorptive action, thus increasing the normal absorption. Secchi remarks further that several lines belonging to metallic

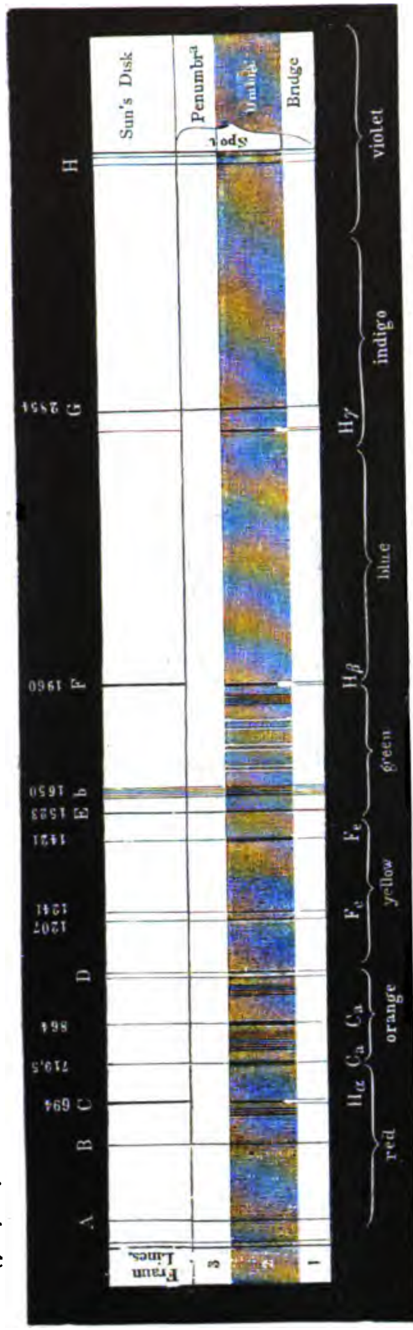


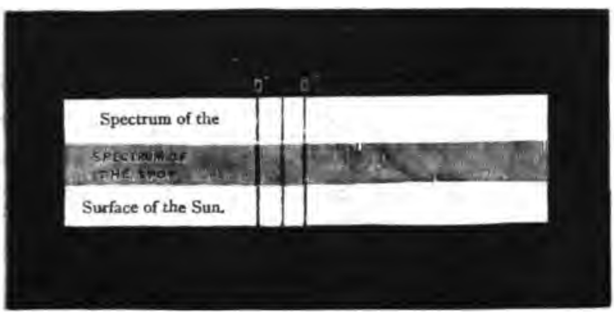
Fig. 160.—Spectrum of the Solar Spot of 11th to 13th April, 1869, as observed by Secchi.

F-line more seldom disappears on account of an adjoining line belonging to iron, which remains unaffected when the hydrogen lines become luminous. Lockyer, on the contrary, maintains that under certain circumstances the F-line disappears as completely as the C-line, and is even occasionally reversed.

When the nucleus is spanned by a bridge or covered by a veil of red clouds the C-line is much diminished in intensity or becomes bright, indicating the presence of fiery streams of hydrogen.

In the interior of the spot considerable changes occur in

FIG. 159.



The D-lines in the Spectrum of a Solar Spot.

the spectrum; the ordinary appearance of the dark lines, and their relative intensity, is completely altered. Some of the least visible lines become black, and of considerable breadth; others appear diffused at the edges, while some remain wholly unchanged. Fig. 160, taken from Secchi's observations of the 11th and 13th of April, 1869, includes most of these phenomena. The dark stripe, No. 2, is the spectrum of the nucleus, in which numerous lines are much increased in width, and additional dark lines and bands appear, one between B and C, two between C and D, and two between E and F, besides three pairs of lines in the

lower stratum is absorbed, and consequently the nucleus appears relatively dark.

71. Spectroscopic Investigations of the Solar Spots.

We have just seen that the telescopic observation of the solar spots has not yielded indubitable evidence as to their nature. But spectroscopic investigation has come to our aid at this point, and has afforded valuable results through the labours of Huggins, Lockyer, Young, and Secchi. For the minute spectroscopic investigation of a spot it is not sufficient to apply the spectroscope in the usual manner upon the sun's image in the focus of the telescope, but it is necessary that the image of the spot itself be thrown upon the slit of the spectroscope. To this end a magnified image of the sun must be formed either by the object-glass of the telescope, or, according to the practice of Secchi, by the object-glass of a microscope. By this arrangement a spectrum is obtained which is traversed longitudinally by a dark band, the spectrum of the nucleus; on either side lies the spectrum of the penumbra, which is somewhat less dark, the breadth of the band depending upon the diameter of the spot. In the spectrum of the spot remarkable changes occur, especially between C and D, where many dark lines increase in breadth and intensity, as shown in the double D-line in Fig. 159.

The spectroscopic investigations of the solar spots, although they have been prosecuted with great industry, have not yet led to any conclusive results.

Secchi remarks that in the neighbourhood of the spots, and especially over the surrounding faculæ, the hydrogen lines are always fainter than over the rest of the sun's surface; sometimes they entirely disappear, and are even reversed. This occurs most frequently in the C-line; the

amount of this fall in temperature is unknown, and must vary greatly in each instance, but must always be very considerable. This disturbance in the solar atmosphere would produce upward and downward currents. According to Zöllner, this motion is upward around the edge of the spot, and its effect is to carry with it the hotter parts of the atmosphere, which, rising above the ordinary level of the sun's surface, form the *faculæ*. The descending current, upon reaching the upper surface of the spots, suffers a fall of temperature as the result of the change in radiation, and, as a necessary consequence, the liberated vapour condenses into clouds. These clouds surround at a certain height the scoriæ-like mass forming the spot, and appear, from the distance at which they are viewed, as penumbra or half-shadow. With a sufficiently high power this penumbra is seen to consist of stratifications radiating towards the centre, and as the spot in some instances is considerably below the upper edge of the penumbra, it is easy to understand that when carried by rotation towards the sun's limb an optical displacement should be produced."

In opposition to the views of Spörer and Zöllner, Secchi puts forth the theory that the solar spots are the result of stormy movements and powerful convulsions in the interior of the sun, in consequence of which its luminous surface is broken through by holes, more or less irregular in form, into which the surrounding photosphere pours. The darkness of the nucleus is explained by the supposition that the luminous photosphere in rushing into the hot cavity passes from the nebulous into the gaseous condition, and thereby loses its luminosity and becomes invisible, and thus the nucleus remains dark, notwithstanding the continuous stream of luminous matter. The depth of the cavity occasions the formation of a thick stratum of gaseous metal at a high temperature, by which much of the light emitted from the

cavities or not.* Professor Spörer, one of the most industrious observers of the solar spots, has been confirmed in the opinion held by Kirchhoff that the spots are cloud-like condensations in the solar atmosphere formed by the radiation of heat, in the same way as vapour in the earth's atmosphere is formed into mist and cloud. When such clouds arise *above* the glowing and luminous surface of the sun they intercept the light, and it naturally follows that as these clouds are irregularly formed, they should also be irregularly condensed or dispersed according as they come in contact with a warmer or cooler stream of gas.

Those physicists who with Faye regard the sun as a non-luminous gaseous ball look upon the spots as rents, openings, or depressions in the *photosphere* or luminous envelope surrounding the *dark* gaseous body of the sun through which the dark body of the sun is allowed to appear.

Spörer has detected in the spots solid products of combustion which are explained by Zöllner to be masses of *scoriæ*, formed on the glowing surface of the sun by an excess of radiation, and dispersed again by the returning equilibrium of the solar atmosphere. "When these disturbances," he remarks, "instead of being local, become almost universal, the conditions are unfavourable to the formation of spots, since there is wanting the chief condition or producing a great fall of temperature through radiation, namely, a clear and tranquil state of the atmosphere. It is not until the air, by the dissolution of the spot, has gradually regained its tranquillity that the process recommences, and thus assumes a periodic character. Each spot by its very existence creates a district in which the temperature is considerably lower than in a locality free from spots. The

* [At Kew and Greenwich photographs have been obtained when a spot was just at the limb. One or two photographs show notches cut out of the limb due to the depression of the spot.]

from its oblique direction eastward. From more than a hundred observations I have been convinced that the spots are in reality cavities, and I therefore have not the slightest remaining doubt on the subject."

Similar observations were made by Alexander Wilson in 1774, as well as by the elder Herschel, by whom the solar spots were regarded as funnel-shaped depressions. Were a spot to form upon the *surface* of the sun, on the eastern limb, the preceding or western part of the penumbra would first come into view, owing to the sun's rotation from east to west; then the western portion of the nucleus would become visible, and gradually increase from west to east, till the eastern portion of the penumbra, the furthest from the line of sight, would be revealed. In the same way, on disappearing round the western limb of the sun, the preceding or western part of the penumbra would first cease to be visible, the western penumbra would then gradually decrease, after which the nucleus would diminish in the direction of west to east, and finally the following or western part of the penumbra would disappear from view.

In reality, the reverse is observed. On the appearance of a spot at the eastern limb, the eastern portion of the penumbra is first visible, then the nucleus in the form of a dark streak, which gradually widens from east to west, till, when the whole of the nucleus is visible, the western side of the penumbra comes into sight. On the disappearance of the spot at the western limb of the sun, the eastern portion of the penumbra, that which is turned towards the centre of the sun's disc, begins to decrease, and the nucleus contracts into a narrow streak, while the western side of the penumbra is scarcely affected. Not till the nucleus is lost to sight does the western penumbra begin to diminish, and finally disappear.

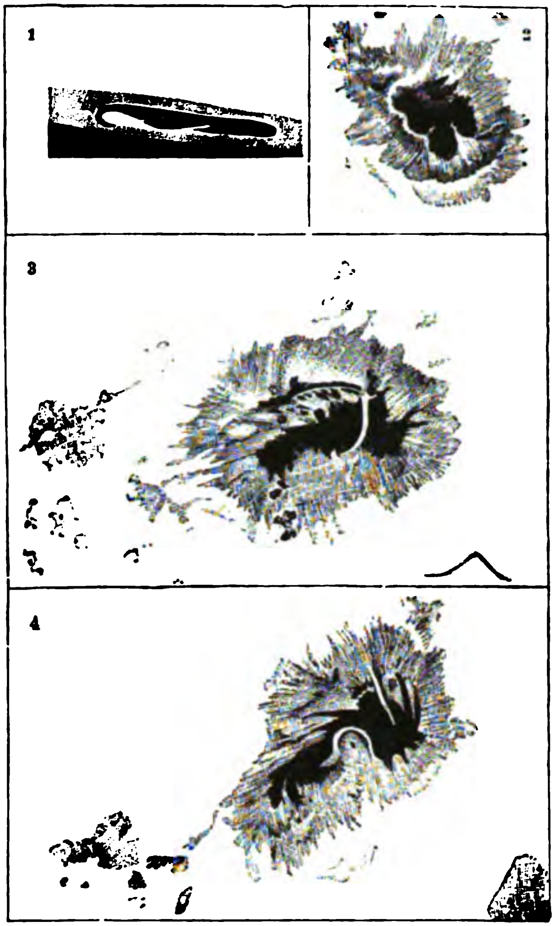
Opinions are still divided as to whether the spots are

70. Speculations as to the Nature of the Solar Spots founded upon Telescopic Observation.

Almost immediately upon the discovery of the solar spots hypotheses were formed as to their nature. Galileo regarded them simply as solar clouds; Cassini supposed them to be solar mountains exposed to view by the occasional sinking of the sea of light. Schülen, pastor of Essingen, near Aalen in Würtemberg, was the first to give expression to the opinion that the solar spots were depressions. "Three large spots," he writes in 1770, "which I saw for the first time on the 26th of March (1770), on the eastern side of the sun a little way from the centre, presented to my view a very remarkable phenomenon. I could plainly distinguish that they were not bodies upon the surface of the sun, floating as dark substances on it, but were *cavities*, the openings to which were darker than the rest of the sun, and were somewhat *conical in form*, leading to a black abyss which showed itself in the middle. In short, depressions and cavities in the solar surface were presented to my view in the clearest manner. The central spot of the three seemed to give most strongly the impression of a cavity. In this spot the hollow was, as in the case of the others, directed towards the centre of the sun, but somewhat obliquely, so that the opening—or expanding entrance—was directed towards the eastern side, and the inner black abyss was partially hidden in consequence of the spot being situated towards the eastern limb. On looking for the spot on the 29th of March, in order to see the western side, the whole of the black nucleus was exposed, as well as the part of the opening which had not been visible while the spot was eastward. This observation appeared to me important, as on both occasions the cavity had the aspect it should have had in perspective

phenomenon that proves not only that the spots are connected with the surface of the sun, but that the sun has a

Fig. 158.



The Great Solar Spot of 1865 (from 7th October to 16th October).

revolution upon its axis. The time of rotation calculated from this data amounts to twenty-five days five hours thirty-eight minutes.

When a spot is observed near the sun's limb in the midst of the surrounding faculæ, it is difficult to avoid the impression that the spot lies in a hollow between bright overhanging mountains; and it was observed by Secchi on the 5th of August, 1865, that the faculæ when they reached the western limb of the sun appeared like small projections and irregularities upon the sharply-defined edge.

Although the connection between the faculæ and the spots is not yet understood, it may be safely concluded that the spots lie deeper in the solar surface than do the faculæ, and that these faculæ are mountainous elevations of the luminous matter of the photosphere which surround the spot like a wall.

The great changes which sometimes occur in a solar spot may be seen from the four drawings (Fig. 158) of the large spot that appeared in 1865, more than 46,000 square miles in area. No. 1 shows the form of the spot on the 7th of October, when it was first visible on the eastern (left) limb of the sun; Nos. 2 and 3 as it appeared on the 10th and 14th of October (central view), when a bridge had been formed across the nucleus; and No. 4 as it was seen on the 16th of October.

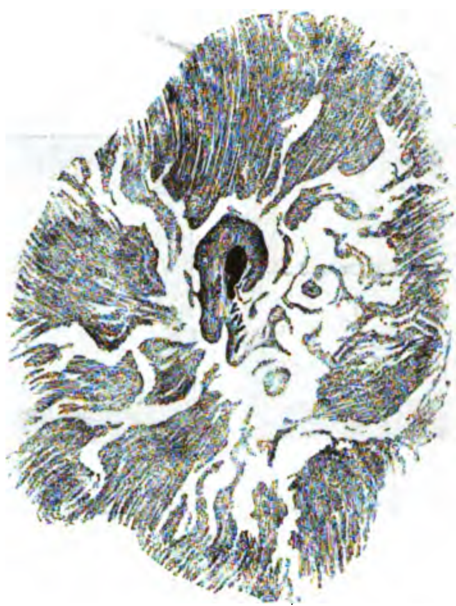
The form of a spot on first appearing on the eastern limb of the sun is that of a narrow dark streak, which for the first few days moves but slowly towards the middle of the sun's disc; its speed afterwards increases till it has accomplished half the journey across the disc. The motion then slowly diminishes until the spot again assumes the form of a narrow streak, and disappears at the opposite (western) limb of the sun. It not unfrequently happens that the same spot which has been observed to disappear on the western limb has in the course of about fourteen days been seen to reappear on the eastern limb, and in the lapse of another fourteen days has disappeared a second time on the western limb, a

isolated faculæ are to be seen around which no spot had yet formed.

The faculæ, like the spots, vary considerably in form; generally they are round and concentrated, but often they have the appearance of long streamers of light (Fig. 157), converging from all sides towards a spot.

The wreathed faculæ are almost always followed in a few

FIG. 157.



Faculæ Surrounding a Spot, after Chacornac.

days by a group of spots; among the vein-like waves of light visible in many places, more especially towards the sun's limb, there is first developed a dull scar-like place out of which the spots are formed, sometimes singly, sometimes in groups; and not unfrequently the formation of a spot may be predicted from the increased intensity of light at that place.

central mass separating the four cavities had resolved itself into a kind of enclosure, upon the surface of which luminous grains seemed scattered."

Solar spots are often surrounded by a border somewhat less dark, termed the penumbra, which in exterior outline follows tolerably closely the outline of the spot itself. Sometimes the penumbra will be traversed by bright bands directed radially towards the central nucleus, which give the spot the appearance as if streams of some luminous matter had broken through the dam formed by the penumbra, to fall

FIG. 155.

FIG. 156.

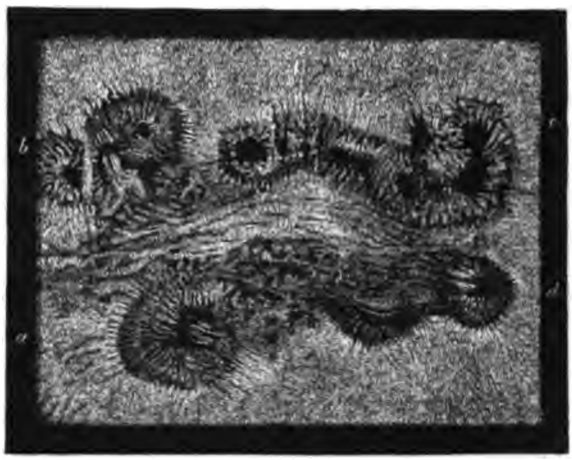
Solar Spot with Radial Furrows in the Penumbra, and with Bridges in the Nucleus.

into the abyss of the nucleus. Even the nucleus itself is often crossed by one or more broad luminous bands or *bridges*, by which it is divided into several portions (Figs. 155 and 156).

Bright places also frequently make their appearance on the sun's surface, which are termed *faculæ.* They are generally the attendants of solar spots, and are especially to be seen at the extreme edge of the penumbra when the spot has reached the sun's limb; that they are not the effect of contrast between the dark spot and the neighbouring brightness is proved by the circumstance that every spot is not accompanied by faculæ, and that very frequently

character. In the evening a second drawing was made, but it resembled the first only in the principal features. In the middle was a moving mass of photosphere; beyond came a ring of gaping rifts, among which the four large ones appeared unchanged in position. On the following day the appearance of the spot had visibly altered. Fig. 154 gives a representation of this new aspect. The four principal centres are still discernible, but they seem to have become

FIG. 154.



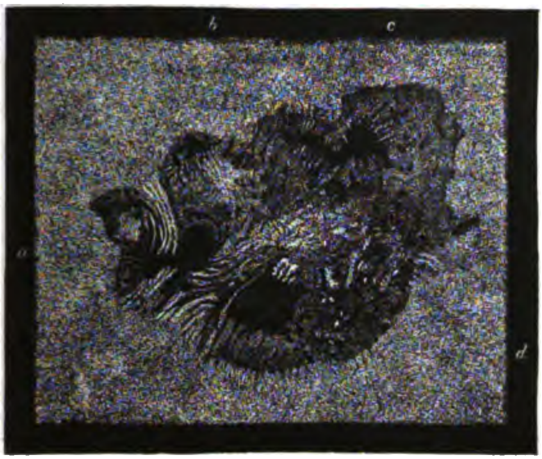
Solar Spot of 30th July, 1865, after Secchi.

merged into two, and to be connected with one another by bound-up rents. The cavity *b* is clearly distinguishable, and is separated from the large rift by the interlacing of the photosphere. The two other cavities *a* and *b* are still connected, but have become more developed: the middle mass is drawn out lengthwise, and its aspect calls to mind that of a fold of cotton-wool which has been pulled out at both ends. In twenty-four hours the dimensions of the spot had considerably changed, the length had almost doubled, and amounted to 147 seconds of arc. The following day the

of flame were entwined in various directions; in the midst of these flames could be clearly distinguished a veil of half light surrounding a depth of deeper blackness.

"In the upper part at *b* was a second centre, smaller than the first, which was sharply defined at the upper edge, and at the lower edge was similarly bordered by a multitude of little tongues of flame. To the right at *c* yawned a wide rift in the form of an S, over which stretched tongues of fire,

Fig. 153.



Solar Spot of 30th July, 1865, after Secchi.

and loose fragments of luminous matter. Finally, in the lower part, on a level with *d*, was another elongated and convoluted chasm, the confused turmoil of which defies description. In the part central to these four cavities was gathered a mass of faculæ and fiery matter having the appearance of a boiling chaldron.

"Everything connected with this spot was in a state of stormy and tumultuous movement. Although the drawing was made as rapidly as possible, yet before it was completed the part first drawn had already assumed quite a different

gregate, they form the *faculæ*, and these generally accompany the spots or precede their formation.

In order to trace the changes through which a spot usually passes, it will be well to follow the description and accompanying drawings by Secchi.

"On the 28th of July, 1865," he remarks, "at the place where the spot burst out there was nothing striking to be noticed, neither pores nor faculæ. On the 29th there were

FIG. 152.

Granulation of the Surface of the Sun.

only to be seen three black specks. On the morning of the 30th, at half-past ten, we were surprised to observe a large spot in the middle of the sun's disc. The mean diameter of this great cavity was 76 sec., or about four and a-half times the diameter of the earth. In the middle of the spot we observed an accumulation of luminous matter, which appeared to be in rotatory motion, and was surrounded by countless rifts. In the midst of this chaos four centres of motion seemed to be distinguishable. To the left at *a* (Fig. 153) there appeared a wide, gaping chasm, around which tongues

But, undoubtedly, the chief objects of interest in solar observations are the sun-spots. These are exceedingly irregular and varied in form, and though they generally remain only a few days, yet they sometimes continue for weeks, or even for months, but never, so far as observation tells us, for a whole year.

In Figs. 153 and 154, representing a solar spot as observed by Secchi, all the features of a spot may be traced,

FIG. 151.

Granulation of the Surface of the Sun.

the penumbra in its various forms, and the granulated luminous appearance of the surrounding surface of the sun. This surface is called the *photosphere*, a name given without reference to any particular theory as to its physical constitution or structure. The photosphere is entirely covered with *pores*, or small spots, less luminous than the other parts: where they congregate, and become conspicuous by forming a black nucleus and shaded penumbra, they constitute the ordinary *solar spot;* where the portions of greater brilliancy than the surrounding parts of the photosphere con-

following it, became on the 5th of November united into one, and left behind them a group of faculæ which were seen close to the edge of the sun on the 8th of November.

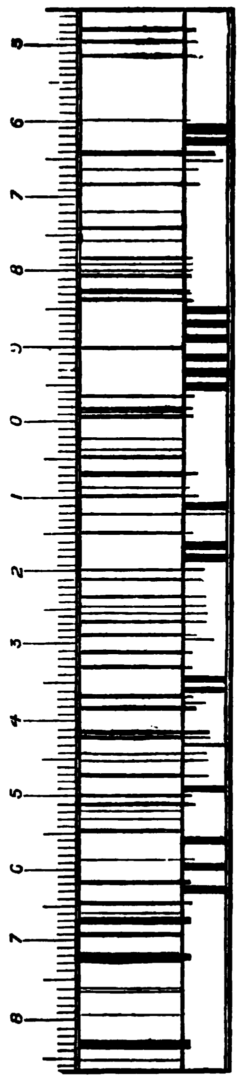


FIG. 163.—Spectrum of a Sun-spot.

It is remarkable that in the spectrum of a spot lines occasionally appear which are not visible in the solar spectrum.

The Astronomer Royal, in a communication to the Astronomical Society, writes regarding the spectrum of a sun-spot observed at the Royal Observatory, Greenwich, 27th and 30th November, 1880:—"Amongst the spectra of sun-spots which have been examined at Greenwich, that of the fine spot which was first seen near the east limb on the 25th of November appears to be quite unique. When examined on the 27th of November, the most striking feature in the spectrum was a number of strong dark lines between *b* and F, to which there appeared to be nothing corresponding in the ordinary spectrum of the photosphere. Under favourable circumstances, however, faint lines were detected in the solar spectrum corresponding to all, or nearly all, of these dark lines in the spot, but none of these are represented either in Kirchhoff's or Ångström's maps, and

they do not appear to correspond to any known element. The dark lines in the spot were fully as broad as b_1 or b_2, being about one-tenth metre in breadth, and somewhat fuzzy, at the edges.

"The following are their wave-lengths, as derived from careful comparison with the lines in Ångström's map:—

5162·3	5118·2	5088·8
5159·7	5116·5	5086·9
5155·9	5111·0	5084·9
5148·9	5095·2	5062·7
5135·3	5093·4	5061·1
5134·0	5091·2	

"The lines at 5129·4, 5112·1, and 5142·2 were much broadened in the spot; D and F were about one-third as broad again, and upwards of 300 lines between D and F were noted as being more or less affected.

"On the 30th of November the above-mentioned bands were not so marked, but the C and F-lines were much broader (about doubled in breadth), and many lines between B and *b* were very much darkened and broadened. The *b* lines were hardly affected.

"The observations were made by Mr. Christie and Mr. Maunder with the half-prism spectroscope, mounted on the great equatorial. A train of two prisms, giving a dispersion of about 80° from A to H, was used, with a magnifying power of 10 on the viewing telescope.

"On the 1st of October, 1880, a strong dark line at W.L. 5146·3, not corresponding to any line in Ångström's map, was seen in the spectrum of two sun-spots. This dark line, though resembling in character those mentioned above, does not correspond in position with any of them.

"The figure (163) represents a portion of Ångström's map of the solar spectrum near *b*, with the spectrum of the sun-spot below, showing the dark bands. In the case of the other lines the length represents the amount by which the line is

broadened—full length corresponding to a line which is doubled in breadth; half length, to one of which the breadth is increased by one half; and so on."

It has been suggested by Vogel that this, as well as the one-sided expansion of some of the lines, may possibly indicate that over the spots the temperature is so far reduced as to allow chemical combinations to take place in the elements passing over them. A similar idea has been expressed by Young in allusion to Schuster's observation, that lines expanded on one side only are characteristic of the spectra of compound substances. With the exception of being brighter, the spectra of faculæ do not differ materially from that of the solar surface. In some faculæ, however, the F-line is somewhat expanded towards the violet.

The results of the spectrum observations* hitherto made, important and valuable as they are, remain as yet too isolated and unconnected with telescopic observation to yield material for explaining the nature of the spots and faculæ. It has, however, been established, that the increase in the width and intensity of the Fraunhofer lines, as well as the appearance of new dark bands in the spectrum of the nucleus, ***are produced by the increased absorptive power of the substances of which the spot is formed.***

When the white light of the sun's nucleus after passing through the absorptive stratum further encounters the component substances of a spot, it undergoes a yet further

* [That the subject of the sun-spot spectra is not exhausted is shown by several important papers which have been communicated to the Royal Society and the Astronomical Society by Mr. Lockyer and Mr. Christie within the last three years. The former observer found whilst studying the spectrum of iron in solar spots that some of the iron lines are expanded and twisted in one direction, whilst others are so in the other direction. As will be seen further on, this indicates motion in opposite directions. The reason of these opposite motions of the same metallic spectrum requires careful consideration.]

absorption. As the lines of calcium and iron are considerably affected in the spectrum of a spot, the sodium lines in a smaller degree, and to some extent those of magnesium, titanium, and barium,* it may be concluded that the solar spots are composed pre-eminently of these vapours, which doubtless occur in layers of varying thickness, and in very different proportions.

That hydrogen gas constitutes an important element in the formation of the spots is shown by the spectrum. The hydrogen lines are most affected in the parts that lie close to the nucleus, in the bridge when one is formed, and in the penumbra. In the spectrum of the bridge (Fig. 160, No. 1) the three characteristic lines Hα, Hβ, Hγ, are ***very bright***, in the spectrum of the penumbra (No. 3) they are often entirely wanting, while in the spectrum of the surface of the sun and of the nucleus (No. 2) they appear as the well-known dark Fraunhofer lines C, F, and the one near to G.

An explanation of this phenomenon is offered by the supposition that hydrogen gas breaks forth from time to time from the interior of the incandescent solar nucleus. Owing to its extreme lightness, this gas would rise in enormous pillars of flame (prominences) over the absorptive vaporous stratum of the photosphere, and, in consequence of the cooling ensuing from expansion, would enter into a variety of chemical combinations, especially with oxygen; the uncombined part would then flow to the side, while that in combination with oxygen (steam) and the other solar substances would form gaseous or vaporous masses, which, from their nature as well as from their continued cooling, would be heavier than the hydrogen gas, and would sink below it.

* [The spectra of spots vary considerably, as Lockyer has shown, and at present the constituents which are more generally found in them must be considered *sub judice*. There seems to be a variation at the time of maximum and minimum sun-spot periods.]

The stream of gas on rising would carry with it a quantity of the substances existing in the sun's nucleus and the surrounding absorptive stratum—the photosphere. If these incandescent substances were present in sufficient quantities, their characteristic lines would be seen as bright lines in the spectrum of the hydrogen flames. During total eclipses such lines have been remarked in the prominences, and are now daily observed upon the sun's disc.

When the force of the gas eruption has somewhat subsided, and the chemical combinations ensue, producing vaporous precipitations, the formation of the spot begins. The denser portions sink and form the *nucleus* of a spot, while the parts less dense constitute the *penumbra*. The vaporous nucleus, though apparently black, transmits a considerable amount of sunlight; indeed, it has been conjectured that the black nucleus of a spot emits four thousand times as much light as an equal area of the full moon. This supposition is confirmed by spectrum analysis, for the blackest nucleus yields a spectrum exhibiting all the details of full sunlight.

Where the spot is broken through by the overflowing masses of the photosphere, a *bridge* is formed which extends as a bright band across the whole of the penumbra. The luminous hydrogen in passing towards the edges of the spot rises above the absorptive stratum of which the bridge is composed, and causes the dark Fraunhofer lines C, F, and one near G, to appear bright; these lines, therefore, in the spectrum of the bridge (Fig. 160, No. 1) are reversed. In the nucleus the hydrogen is too small in quantity and too low in temperature for its lines $H\alpha$, $H\beta$, $H\gamma$ to overpower the dark Fraunhofer lines C, F, and the one near G, or even to weaken them perceptibly; in the penumbra, on the other hand, the hydrogen is in sufficient quantity, and of a sufficiently high temperature, to cause its three bright lines to equal in intensity the neighbouring parts of the spectrum,

and thus to be invisible. In the spectrum of the bridge (1) these lines are generally bright, in that of the nucleus (2) they remain dark, while they are frequently absent in the spectrum of the penumbra.

The remarkable changes occurring in the lines of hydrogen, magnesium, sodium, calcium, and iron in the spectrum of the nucleus, seem to show that the new combinations are disposed in layers according to their specific gravity. Thus hydrogen gas occupies the highest stratum; aqueous vapour, magnesium, and sodium occur in thinner layers below; while the lowest and densest stratum is composed of the heavier vapours of calcium, titanium, and iron.

The formation of a spot will accordingly immediately follow an eruption of hydrogen; the spot itself is a cloudy, luminous mass, probably of a semi-fluid consistency, composed of many constituents which sink a certain depth into the photosphere, partially intercepting its light, and presenting the appearance of a dark mass projected upon the solar disc, in the same way as the intense oxyhydrogen lime-light appears black when seen against the sun.

The enormous dimensions of these dense masses of vapour account for the length of time the spots continue visible, not unfrequently during several rotations of the sun. Their disappearance is to be explained partly by the substance of the photosphere flowing into the cavity of the spot, and partly by the complete subsidence of the vapours into the nucleus of the sun, where, in consequence of the enormous heat, the compound substances which may exist in them are broken up into their original elements.

These conjectures are not offered as a complete explanation of the phenomena of a solar spot, but to throw light upon the results obtained by spectrum observations, and to bring them into harmony with the phenomena observed during total solar eclipses.

72. Total Solar Eclipses.

The chief obstacle to an increased knowledge of the nature of the sun is the blinding light of the photosphere, which overpowers the wonderful phenomena unceasingly occurring upon the solar surface. During the brief obscuration of the sun's disc at the time of a *total solar eclipse*, when the dark body of the moon covers—but scarcely more than covers—the entire surface of the sun, the brilliant phenomena taking place in the solar atmosphere become visible around the sun's limb.

The aspect presented to the unassisted eye by a total solar eclipse is shown in Fig. 164, representing the eclipse of the 7th of August, 1869, as seen by Dr. Gould at Des Moines, in North America.

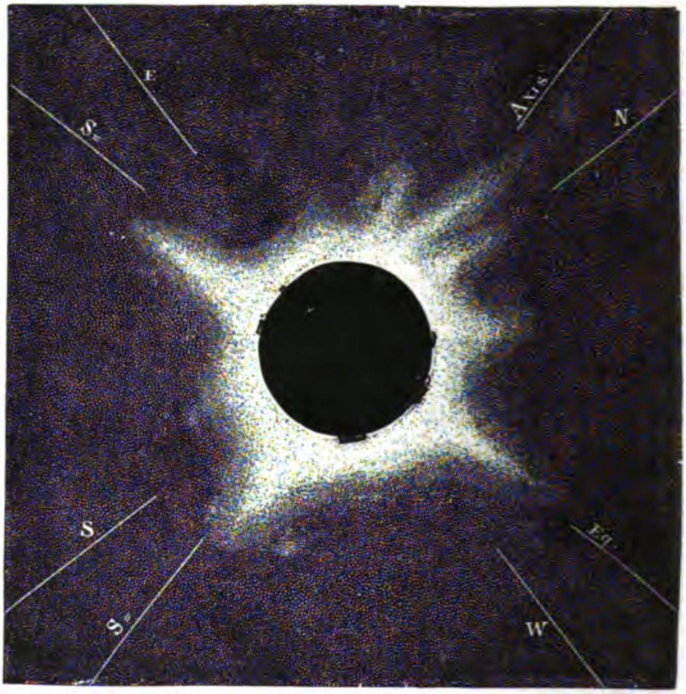
The sharply-defined black edge of the moon appears surrounded by a narrow but very brilliant ring of light of silver whiteness, called the *corona*. From the corona faint rays of light, irregular in length and breadth, stream out, surrounding the moon's disc like a glory, whence this *crown of rays* * is usually designated the glory or *halo*. The dark projections partly covering the corona are the *prominences*, which are cloud-like masses of a rose or pale coral colour, disposed either singly or in groups at various places on the sun's limb. They pierce the corona in the most wonderful forms, sometimes as single out-growths of enormous height, sometimes as low projections spreading far along the moon's limb. The prominences are generally first seen on the eastern (left) side of the sun, where at the commencement of totality the moon barely covers the sun's edge, and the space immediately beyond is still uncovered; as the moon

* [It is more usual to designate the whole of these extra solar appendages as the corona. Recent evidence confirms the opinion that there is an inner as well as an outer corona.]

advances to the east (E), the space immediately surrounding the western limb (W) of the sun becomes exposed, and the prominences on that side begin to reveal themselves.

These remarkable phenomena are accumulations of the luminous gaseous material by which the solar body is sur-

FIG. 164.



Total Solar Eclipse of 7th August, 1869.

rounded; it cannot, therefore, be surprising that their forms have been seen to change even during the short duration of totality. The enormous height to which these pillars of gas extend beyond the limb of the sun in some instances exceeds 90,000 miles.

A total solar eclipse of several minutes' duration is of rare

occurrence, and the eclipse of the 18th of August, 1868, which offered a totality of from five to six minutes, excited universal attention. The zone of total darkness extended, in a breadth of more than a hundred miles, from Aden to Torres Straits, passing over the southern parts of Asia. National preparations were entered into for its adequate

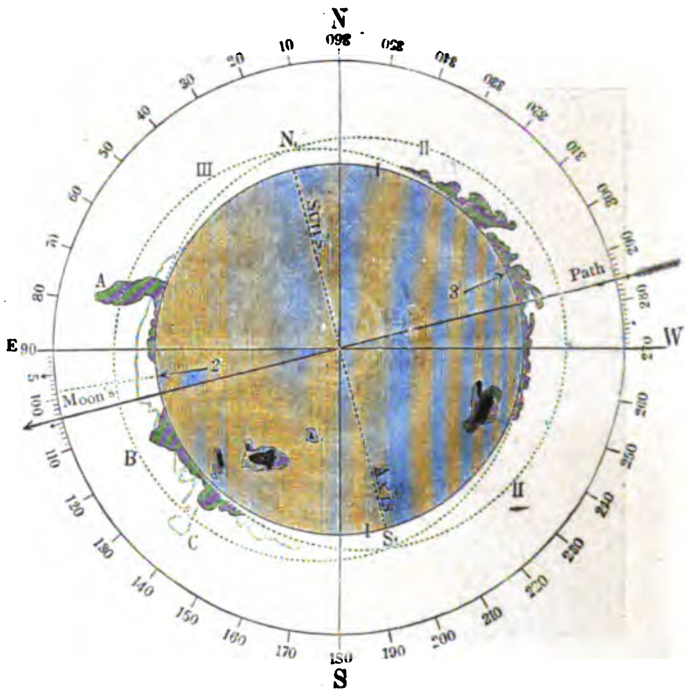
FIG. 165.

Total Solar Eclipse of 18th August, 1868 (Aden).

observation, and numerous expeditions sent out to selected stations by the governments of England, Germany, Austria, etc. Fig. 165 represents the first phase of totality, as photographed at Aden by Dr. Vogel. The great prominence on the eastern limb of the sun had an elevation of about one-fourteenth of the sun's diameter, or about 60,000 miles.

Plate II. contains copies of two out of the six photographs taken by Colonel Tennant at Guntoör. By superposing copies of these six photographs, Mr. De La Rue has constructed the map of the phenomena given in Fig. 166. The shaded disc I, I represents the sun; II, II denotes the moon's disc at the moment of second contact 2 (first inner

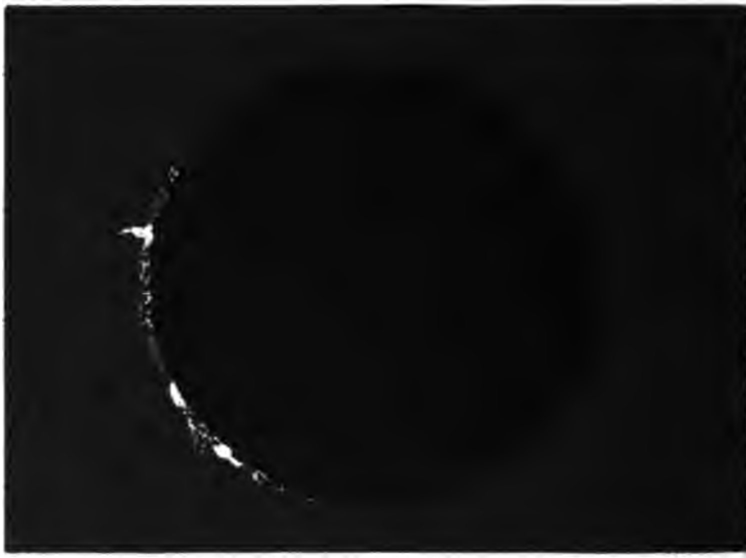
FIG. 166.



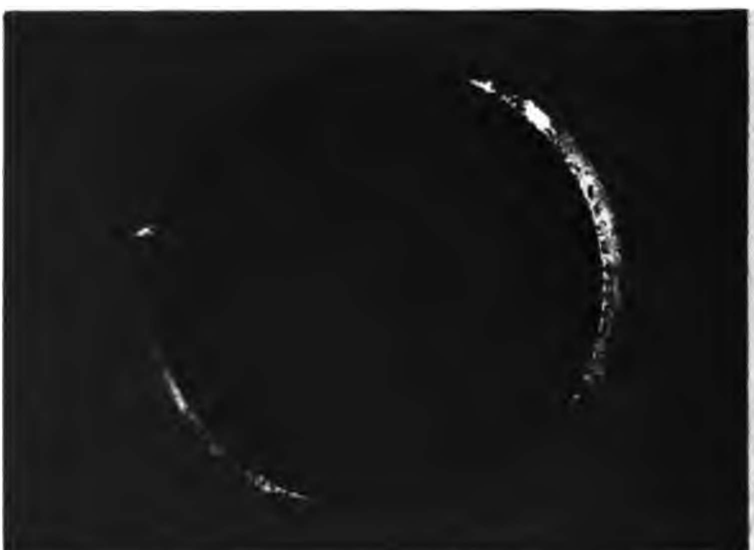
Tennant's Photographic Pictures collected into one Drawing.

contact), when the totality began, and the large prominence A appeared on the sun's eastern limb; III, III is the moon's disc at the third contact 3 (second inner contact). The drawing also gives the position of the sun's axis, the direction in which the moon's centre was travelling from west to east, and indicates, by the dotted lines over the

TOTAL SOLAR ECLIPSE (India)
1868 August. 18

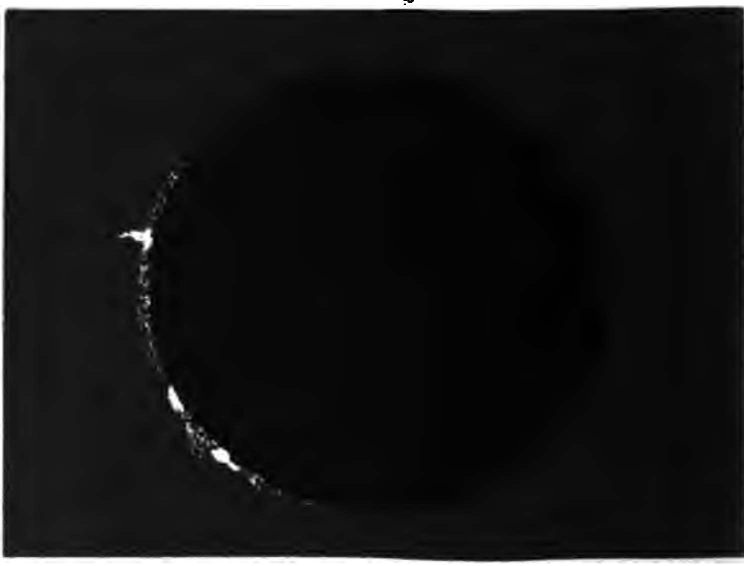


Guntoor (Col[l]. Tennant) Commencement of Totality.
Time of Exposure 5 Sec.

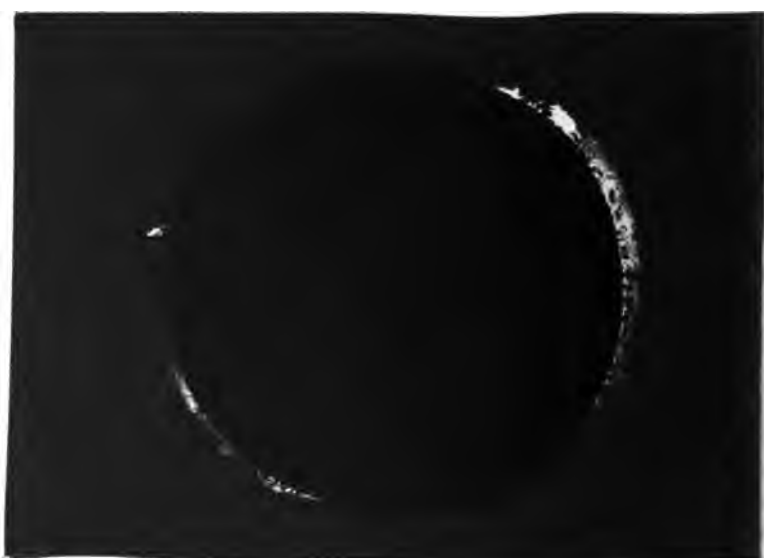


Guntoor (Col[l]. Tennant) Towards the end of Totality
Time of Exposure 1 Sec.

TOTAL SOLAR ECLIPSE (India)
1868 August. 18.



Guntoor (Col.l Tennant) Commencement of Totality
Time of Exposure 5 Sec.

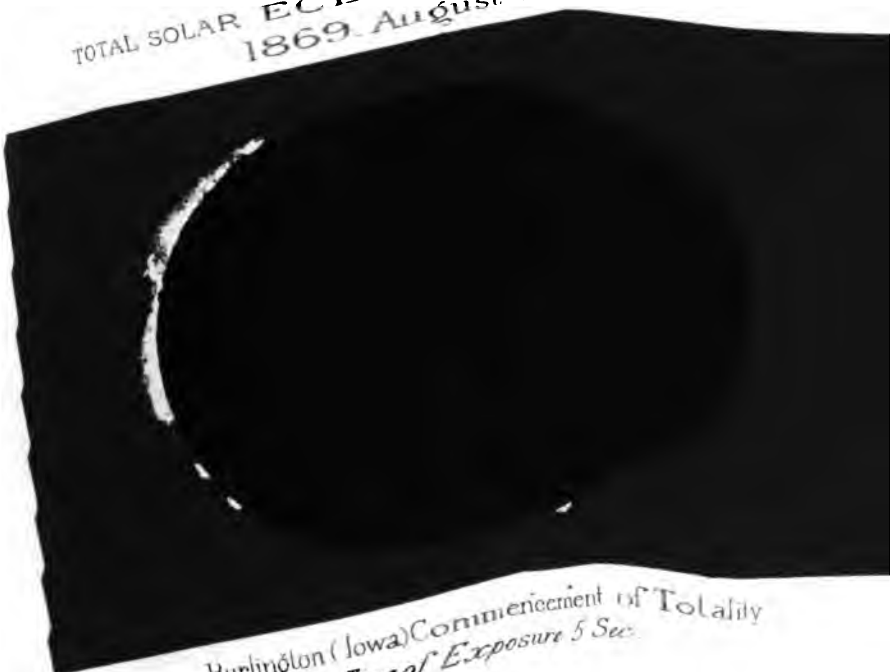


Guntoor (Col.l Tennant) Towards the end of Totality
Time of Exposure 1 Sec.

W. H. WESLEY, LITH.

F

TOTAL SOLAR ECLIPSE (North America)
1869 August 7.



Burlington (Iowa) Commencement of Totality
Time of Exposure 5 Sec.

Burlington (Iowa) Towards the end of Totality
Time of Exposure 7 Sec.

glass of a telescope of $5\frac{1}{2}$ inches aperture, and exposed forty seconds. A representation of this photograph is given in Fig. 167.

The corona appeared to consist of two principal portions —the inner one, next to the sun, was nearly annular, reaching an elevation of about 1′, and in colour of a pure silvery

FIG. 168.

The Corona of the Eclipse of 7th August, 1869, at Des Moines.

whiteness; the outer portion consisted of rays, some of which grouped themselves into five star-like points, while the others assumed the appearance of radiations, and were the most sharply defined. The star-like rays attained a height equal to half the diameter of the sun.

Another picture of the same eclipse is given in Fig. 168

The Corona during a Total Solar Eclipse.

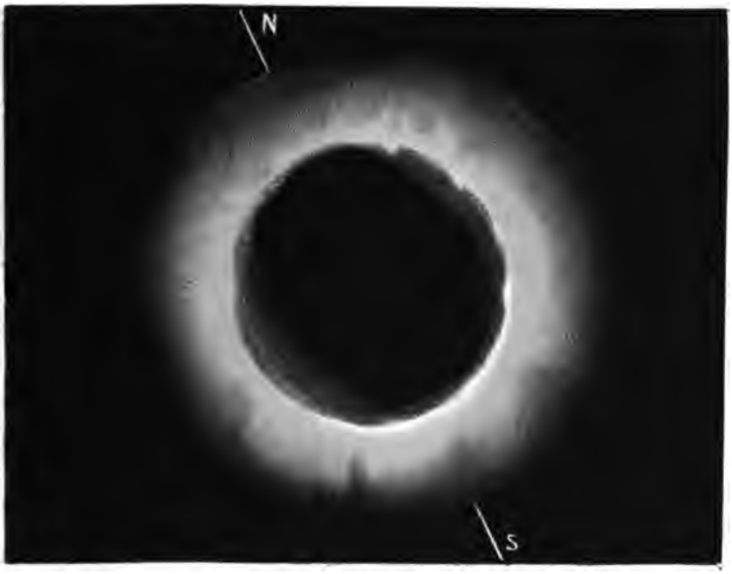
1.

Photographed by P. Secchi at Desierto, (Spain) 18. July 1860. (Exposure. 40 Sec.)

2.

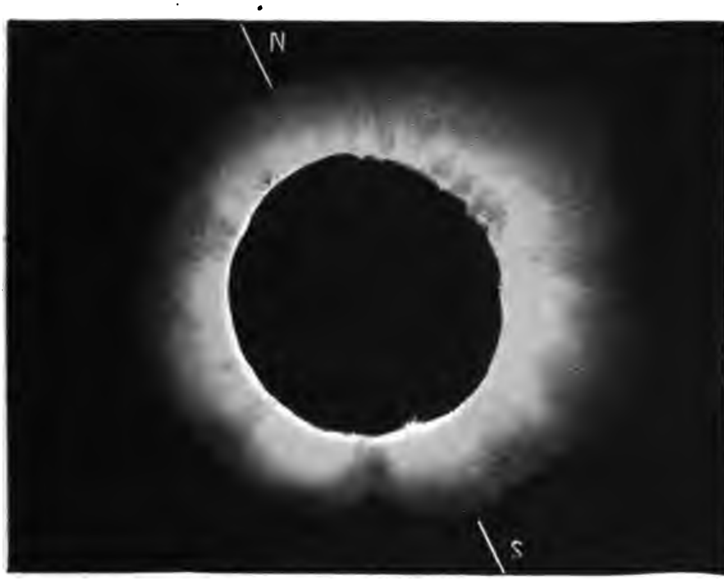
Photographed by Whipple *at Shelbyville (Kentucky.) 7. August 1869. (Exposure 40 Sec.)*

3.



Photographed by Willard *at Xerez (Spain)*
22. December 1870. (Exposure. 90 Sec.)

4



Photographed by Brothers *at Syracuse (Sicily.)*
22. December 1870. (Exposure. 8 Sec.)

from a photograph by Professor Eastman, at Des Moines. It was taken at the commencement of the totality, when the corona made its appearance as a light of silvery whiteness, with an exceedingly tender flush of a greenish-violet hue at the extreme edges, and not the slightest change was perceptible during totality in the colour, the outline, or the position of the rays—an observation confirmed by several observers.

Plate IV. exhibits the corona in its natural colours from photographs by various observers. No. 1 by Padre Secchi at Desierto (Spain) during the eclipse of 18th July, 1860; No 2 by Mr. Whipple at Shelbyville during that of 7th August, 1869; and Nos. 3 and 4 by Mr. Willard at Cadiz, and by Mr. Brothers at Syracuse, during the eclipse of 22nd December, 1870. The exposure varied, as will be seen, from eight seconds to ninety seconds.

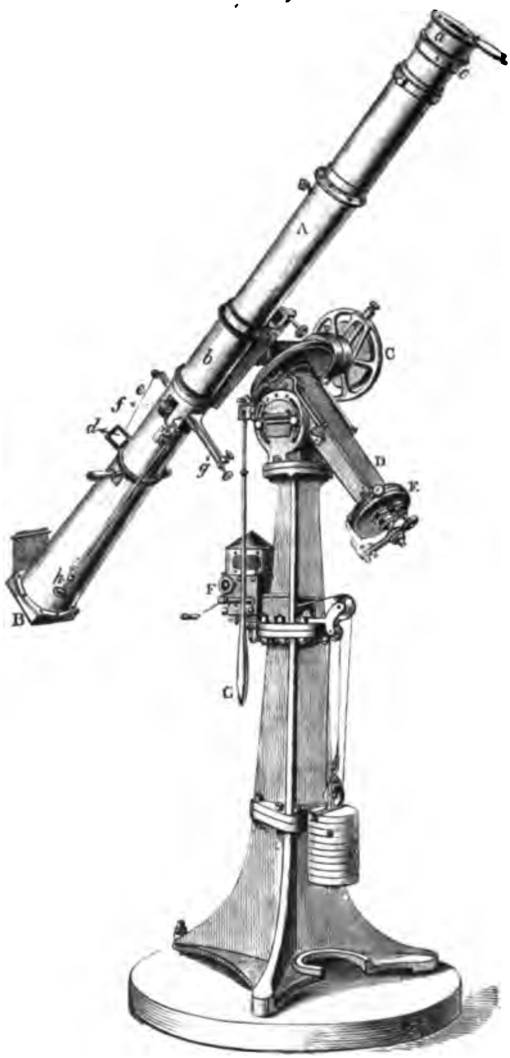
73. Photographic Pictures of Total Solar Eclipses.

[In the preceding section there have been many allusions to the photographic pictures of eclipses. Photography was first employed at the great solar eclipse of the 28th of July, 1851, and has since been applied to almost every succeeding eclipse that has been observed. Dr. Busch used a telescope of 2 feet 6 inches focal length, and an aperture of 2·4 inches for the purpose, and the sensitive surface was a daguerreotype plate. In 1860 Padre Secchi obtained photographs by the wet collodion process in a telescope of about 10 feet focal length, and at the same eclipse Warren de la Rue used the new photoheliograph for the same purpose. As this class of instrument is in use at the principal observatories for taking sun pictures, we give a short description and engraving of the latest pattern as taken by Abney's "Text Book of Photography"* (Fig. 169).

* [Longmans.]

At *a* is a lens of about 4 feet focus, having a cell on which is cut a very fine screw, so fine and accurate, indeed, that the lens can be caused to advance or recede from B by the $\frac{1}{1000}$ part of an inch by turning the cell through a portion of a turn. About *f* is the principal focus of the lens, at which point are placed cross wires or a ruled grating, the focus of which can be accurately obtained by a slow-motion screw, turned by the handle H. This moves an inner tube in which the diaphragm holding the wires is inserted. Immediately in front of *f*, and running in a pair of grooves, is the exposing screen, in which there is an adjustable opening or slit. At *g* is a spiral spring which tends to

FIG. 169.



Dallmeyer's Photoheliograph.

keep the slit below the point where the image is formed, whilst at *e* is a little pulley, over which runs a thread attached to the top of the exposing diaphragm, and terminating by a loop. The preliminaries to exposure are to draw the diaphragm up to *e* by the thread, and then to place the loop over a pin (not shown in the figure); this brings the slit above the place where the image is formed. The exposure is given by cutting the thread; the spring *g* pulls the diaphragm towards it, and the slit traverses the image. The duration of exposure can be regulated between $\frac{1}{20}$ and $\frac{1}{100}$ part of a second, a margin sufficiently wide to suit the sun as seen through almost any condition of the atmosphere.

Below *f* is placed a magnifying lens which takes the form known as "the rapid rectilinear." Its function is the same as that of an eye-piece in a telescope, and by altering the distance between its optical centre and the focus of the object-glass, any size of image can be produced. In the instrument under consideration, the diameter of the sun's image has been fixed approximately at 4 inches, and consequently the adjustments of the secondary lens are made so that there cannot be much variation from those dimensions. B is the holder in which the slide carrying the sensitive plate is placed. Some of the means of adjustment have already been pointed out; a further one is that of the secondary magnifier, which by a slow-motion screw can be caused to recede or advance along the axis of the telescope. It will be seen that every means of securing a sharp image of the sun, together with that of the cross-wires, or ruled gratings, is to be found in the instrument. The telescope is mounted equatorially, D being the polar axis, C and E the declination and right ascension circles, and F the clock movement. By means of G a motion can be given to the tube in right ascension, and by a corresponding handle

attached to the tube (and not shown in the figure) a motion in declination. The greatest danger to the accuracy of this instrument is distortion, through the multiplication of lenses, and the risk that exists of these not being properly centred. When attention has been paid to this, as it has been by the eminent optician who has constructed them, they leave little to be desired.

The photographs taken with this instrument, during an exposure of 60 seconds, show but little signs of the corona, and it was not till the eclipse of May 1883 that a similar instrument was employed. In the expedition the English observers, who went to the Caroline Islands under the auspices of the Royal Society, and under the direction of a committee of the same society, were more successful, obtaining images of the inner corona. This success was due to using the more sensitive gelatine process, which is now extant. In the eclipses of 1868, 1869, 1870, 1871, 1875, 1878, 1882, and 1883, photographs were taken which have all added to our knowledge of the corona, but it was only in the last four years that photography has been at all able to compete with eye observations in depicting the extent of the corona. The reason for this is that with the older photographic processes the light emitted is so feeble at the distance of a solar diameter from the moon's edge that the length of exposure that can be given was not sufficient to impress the sensitive plate. Within the last four or five years the new gelatine process has been brought to such a state of perfection, that the plates are, in reality, fifty or a hundred times more sensitive than the collodion process. Thus an exposure of one second with a gelatine plate is equivalent to an exposure of a minute with the wet collodion process. Hence for the production of photographic pictures this latest improvement in photography has practically converted a solar eclipse from seconds to minutes. The eclipse

of May 1882, which was observed in Egypt by parties of almost every nation, only lasted about seventy seconds, and yet in that brief space of time the English observers, who alone employed photography, were enabled to secure three excellent photographs of the corona, the photographic impressions being apparently coterminous with the visual impression of the observers.

These pictures were obtained with an ordinary lens by Dallmeyer, of about 5½ feet focal length, and 4 inches aperture; and it seems to be the opinion of most solar physicists that this form of lens is better than using the objective of a telescope, as it is specially constructed for photographic purposes, which an ordinary telescope's objective is not.

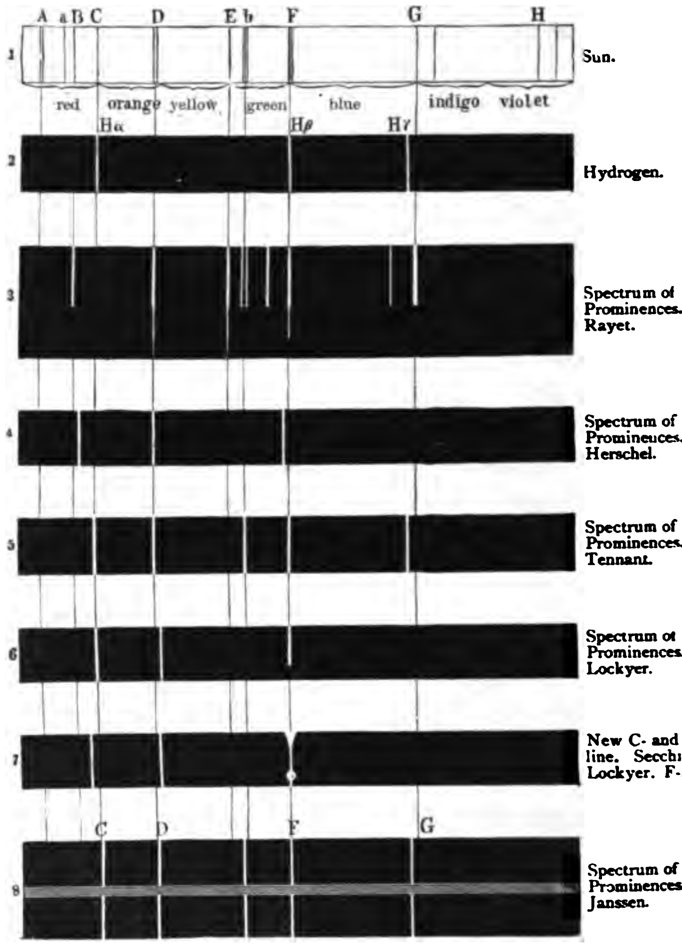
In the eclipse of May 1883 the same instrument was used as in 1882, and in addition, as already has been said, the photoheliograph, which also gave fair results, but did not show the same coronal extension which the smaller-sized lunar image gave.]

74. The Prominences and their Spectra.

In the total eclipse of the 18th of August, 1868, the spectrum of the prominences was observed by Herschel at Jamkandi, by Haig at Beejapoor, by Tennant and Janssen at Guntoor, by Rayet and Hall at Wha Tonne, and was found by these observers to consist of a few bright lines, from which they concluded that these forms are composed of *luminous gases* of which hydrogen is the chief constituent. The spectrum of this gas is characterised, as is well known, by three bright lines (Plate XIV., No. 6), *red*, coincident with the Fraunhofer line C; *greenish-blue*, coincident with the F-line; and *dark-blue*, in the vicinity of the line G (*vide* Fig. 170, No. 2).

Fig. 170 contains, in addition to the two comparison spectra No. 1 (the principal lines of the solar spectrum)

FIG. 170.



Various Spectra of the Prominences.

and No. 2 (the principal lines of hydrogen), the spectra of the prominences Nos. 3, 4, 5, and 6, as observed by Rayet, Herschel, Tennant, and Lockyer.

Rayet, who kept his direct-vision spectroscope pointed exclusively to the great prominence, and employed the instrument in all positions, perceived nine bright lines, consisting of those corresponding to the dark lines B, D, E, *b*, F, G, of a green line between *b* and F, and a blue one near G (No. 3). These lines appeared very bright upon the dark background, so that their position could be determined with ease. The bright lines D, E, F were seen to be prolonged below the rest, as finer and fainter lines, which seems to indicate that the glowing gas extends far into the sun's atmosphere in a state of extreme rarefaction.

Herschel (No. 4), with a spectroscope specially constructed, observed in the spectrum of the prominence three very brilliant lines, of which the orange line coincided with D, while the red line was not coincident with either B or C, nor did the blue line coincide with F.

Tennant (No. 5) employed a spectroscope similar to that used by Huggins in his investigations on the spectra of the nebulæ and the fixed stars. The spectrum of the prominence appeared to consist of five bright lines, three of which were in exact coincidence with C, D, and *b*, while the greenish-blue line lay very near to F, and the dark blue line near to G. Time did not allow of a more accurate measurement of these two doubtful lines, but the observations of Rayet seem to show that the first of them was coincident with F, and the other with the hydrogen line Hγ, near to G.

Janssen, in preparing for observation, placed the slit on the advancing limb of the moon, at a tangent to the point where the sun would disappear. With the extinction of the last rays, two new spectra started into view, each consisting of five or six bright lines (Fig. 170, No. 8); the lines were red, yellow, green, blue, and violet, and the two spectra, which were separated by a dark space, were exactly coincident, line for line. When Janssen left the spectroscope

to look for a moment through a small telescope, he saw that both spectra belonged to two magnificent prominences which shone out at the black edge of the moon to the right and left of the point where the last ray of sunlight had disappeared. One of these attained a height of 3′, and resembled the flame of a furnace as it breaks forth vehemently under the influence of a powerful blast; the other presented the appearance of an extended chain of snow mountains, which seemed to rest on the moon's limb, and glowed as if illuminated by the red light of the setting sun. As the brightest lines of the spectrum coincided with the Fraunhofer-lines C and F, Janssen declared at once that hydrogen gas forms an important element in the constitution of the prominences, and this discovery he announced in a telegram to Europe.

The result of the spectrum observations of the prominences made on the 18th of August, 1868, is as follows:—

1. The spectrum of the prominences consists of some bright lines of intense brilliancy, among which the hydrogen lines $H\alpha = C$, $H\beta = F$, and $H\gamma$, near to G, are especially noticeable.

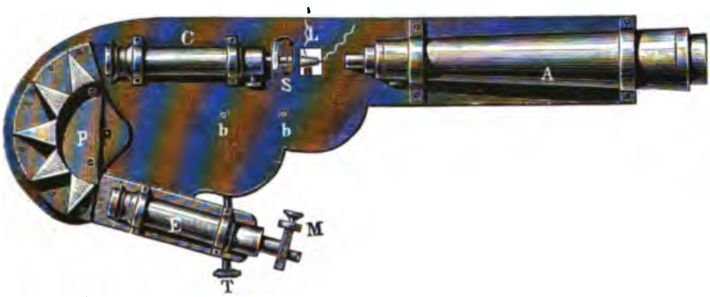
2. The prominences are masses of luminous gas, principally hydrogen; they envelop the entire surface of the solar body, sometimes in a low stratum extending over large tracts of the sun's surface, sometimes in accumulated masses rising at certain localities to a height of more than 80,000 miles.

In the eclipse of the 7th of August, 1869, the spectra of the prominences were investigated by Professor Harkness at Des Moines, and by Professor Young at Burlington. Professor Harkness employed an ordinary spectroscope, with a single prism of 60°, and furnished with a micrometer. Owing to the small dispersive power of the instrument, great accuracy in the measures could not be ensured. By means of the Fraunhofer lines, Harkness compared the

divisions of his micrometer with the millimetre numbers in Kirchhoff's map, and marked the bright lines seen in the prominences given in Fig. 168, by the following numbers of Kirchhoff's scale:—

Prominence *a* gave approximately the lines:
693, 1007, 1497 (Kirchhoff).
Prominence *c* gave approximately the lines:
693, 1007, 1497, ——, 2069.
Prominence *e* gave approximately the lines:
693, 1007, 1497, 1611, 2069, 2770.
Prominence *f* gave approximately the lines:
693, 1007, 1497, ——, 2069, 2770.

FIG. 171.



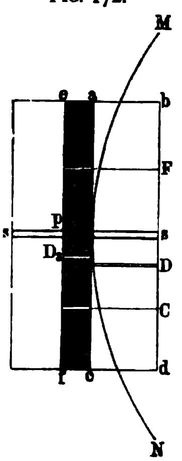
Young's Telespectroscope.

If these readings, though only approximately correct, be compared with Kirchhoff's numbers, it will be found that the bright lines observed may very probably have been as follows: 694=C (Hα), 1017=D_3 (beyond D_2), 2080=F (Hβ), 2796=Hγ, as well as the line 1474 (instead of 1497), less refrangible than E.

The measurements made by Young were much more complete: he was provided with an instrument consisting of five prisms of 45° each, the lateral surfaces of $2\frac{1}{4}$ and $3\frac{1}{4}$ inches, as shown in Fig. 171; the compound spectroscope P was connected with the telescope A, a comet-seeker of 4 inches aperture and 30 inches focus. The collimator C

was furnished with an adjustable slit one-eighth of an inch in length, through one-half of which the comparison prism introduced into the instrument the light of any terrestrial substance; by means of the conducting wires L, the platinum electrodes could be placed in connection with an induction coil. Immediately in front of the slit there was placed at S a divided disc, in the centre of which was a circular opening one-eighth of an inch wide, by which the image of the sun could be kept exactly on the slit, and any portion of the solar image directed upon it at will. The dispersive power of the five prisms amounted to 80° between the lines A and H, and the total deviation for the D-line nearly to 165°. The prisms were carefully adjusted on to the plate P, which was secured to the telescope A by the bolts *b, b,* in such a manner that the central lines in the field of view, embracing from D to E, should be in the most advantageous position. By the micrometer screw T, the telescope E, turning upon a pivot, could be directed upon any of the lines of the spectrum; the eye-piece was furnished with a micrometer, M.

FIG. 172.



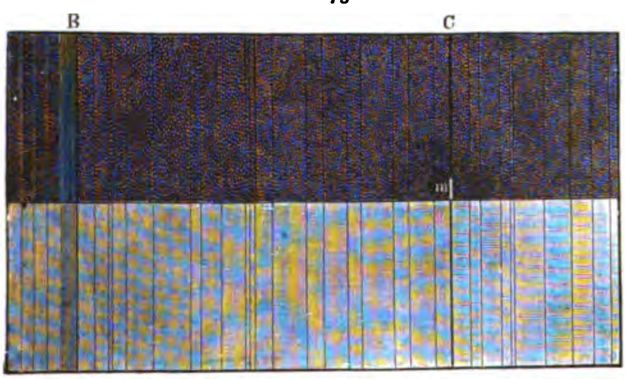
Spectrum of Prominences.

The solar spectrum appeared about an inch and three-quarters in width, and 45 inches in length, and showed all the lines contained in Kirchhoff's map. The readings of the instrument had been compared with Kirchhoff's maps by repeated measurements at forty-two intervals between the principal lines along the whole length of the spectrum from A to G.

Before the commencement of totality, the slit *s s* (Fig. 172) was placed on the limb M N of the sun, in a perpendicular

direction to the tangent *a c*, at that point where, by the advance of the moon on to the sun's disc (in an inverting telescope at the left side), the first contact would take place. With such an arrangement the spectrum consists of two halves in juxtaposition, one of which is the intense solar spectrum *a b c d*, and the other the faint spectrum *a e f c* of the air rendered through dispersion extremely pale. Both spectra exhibit the Fraunhofer lines, as shown in Fig. 173, representing the portion of the spectrum between B and C.

FIG. 173.



Young's Observation of the Prominence-Spectrum.

When the one half of the slit falls upon a prominence, *p*, the *bright* lines of the luminous gases in the prominence are seen upon the faint spectrum of the atmosphere, the hydrogen lines Hα (red) upon C, Hβ (green) upon F, and Hγ (blue) near G, as well as the bright lines of the other incandescent substances that may be present.

Before the moon's entrance on the sun's disc, Young observed, as he directed the instrument upon the line C, a very bright red line, *m*, upon the faint air spectrum, forming an exact prolongation of the dark line C of the solar spectrum, an evidence that at this spot the sun was surrounded by a stratum of luminous hydrogen, the height

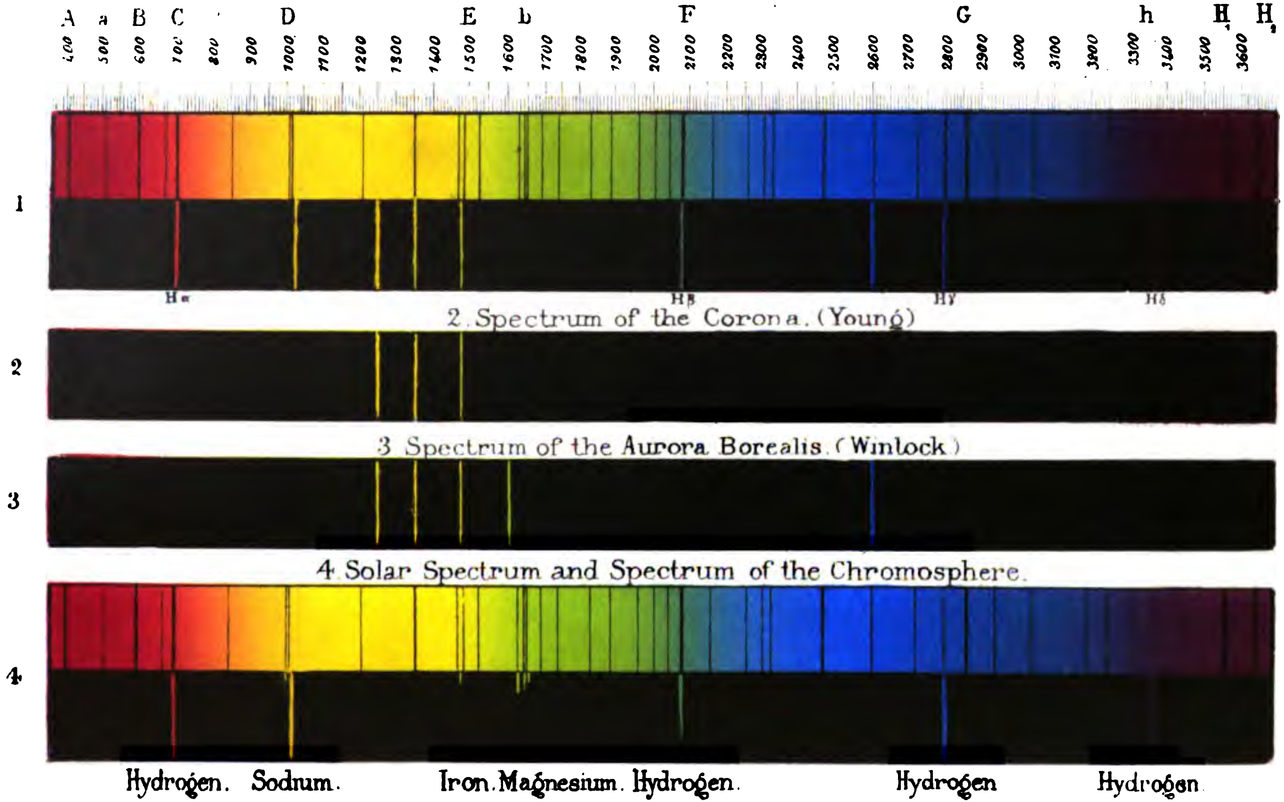
of which, reckoned by the length of the line *m*, must have been from 5,000 to 12,500 miles.

Now it is evident that the moon in approaching the sun must first pass over the stratum of hydrogen. The entrance of the moon upon this stratum is revealed by the shortening of the bright red line *m*, and the disappearance of this line gives the exact moment of the first contact of the moon with the body of the sun. The same phenomenon may be observed, though less conveniently, with the F-line.

This plan of observation had already been devised in theory by Faye, who had suggested it as an accurate means of observing the first contact with the sun's limb of the moon, Venus, or any other heavenly body. Shortly before totality, the slit was directed on to the prominence marked *d* in Fig. 168, and the line C brought into the field of view. With the commencement of totality, the red line Hα became exceedingly intense, but owing to the slight elevation of the prominence, it did not extend fully across the spectrum. No bright lines were perceptible either between C and A or between C and D. Immediately beyond the second sodium line (D_2) appeared the orange-coloured line D_3 on 1017·5 of Kirchhoff's scale, which was followed immediately by two faint yellowish-green lines, estimated at 1250 ± 30 and 1350 ± 20 (Kirchhoff). The green line following at 1474 (K.) was very bright, though fainter than C and D_3; it reached across the spectrum, and *remained unchanged* when the slit was turned from the prominence to the corona, while the line D_3 disappeared. It was thus evident that this line did not belong exclusively to the spectrum of the prominence, but also to that of the corona. Young is of opinion that the two preceding faint lines remained also unaffected; and he had a suspicion that they belonged also to the spectrum of the corona, which was observed simultaneously with that of the prominence. While the slit was

Pl.V.

1 Solar Spectrum and Spectrum of the Prominences, during a total Eclipse



M&N. Hanhart, Chromolith.

directed upon the prominence *e* (Fig. 168), the magnesium lines *b* were not visible, so that no bright lines were perceived at this part of the spectrum. The greenish-blue line (Hβ) was truly splendid, wide at the base, and terminating above in a point; it was followed by a blue line at 2602 $\pm$ 2 (K.) almost as bright as the green line 1474, by the third hydrogen line Hγ, near G at 2796 (K.), and finally by the very distinct but much less bright hydrogen line *h* (Hδ) at 3370·1 (K.).

The nine bright lines observed by Young in the spectrum of the prominences are given in their natural colours in Plate V., No. 1, and they afford an accurate representation of the spectrum of a prominence as it appears during the totality of a solar eclipse. The solar spectrum with Kirchhoff's scale is given above. During totality the solar spectrum is invisible, and is replaced by a faint continuous spectrum without dark lines, which adjoins the spectrum of the prominence, and is doubtless due to the corona.

The bright prominence-lines, observed by Young, correspond with the following numbers of Kirchhoff's scale:—

1. 694 . . . C = Hα.
2. 1017·5 . . D_3 (belonging neither to hydrogen nor sodium).
3. 1250 $\pm$ 20 } Apparently belonging to the corona.
4. 1350 $\pm$ 20 }
5. 1474 }
6. 2080 . . . F = Hβ.
7. 2602 $\pm$ 2 (observed also by Capt. Herschel between F and G during the eclipse of the 18th of August, 1868).
8. 2796 . . . Hγ.
9. 3370·1 . . *h* = Hδ.

[The latest determinations of lines in the prominences have been made by Abney and Schuster from photographs of the prominence and corona spectra, taken in May 1882, in Egypt. Two methods were adopted: one with a slitless spectroscope in which the bright ring round the moon acted as

a circular slit, and the other by projecting an image of the sun on the slit of a spectroscope. By the former method the following lines were determined:—

A line low down in the infra-red,

8240 ?	4861 (F)	4101 (*h*)
6562 (C)	4471 (*f*)	3968 (H)
5875 (D_3)	4394	3933 (K)
5315 (1474, Kirchhoff)	4340 (Hy)	

And many lines in the ultra-violet.

In the prominences which the slit of the spectroscope happened to cut, the following have been determined:—

4861 (F)	3888 H	3708 H
4473 (*f*)	3859 ± 6	3699 H
4340 Hy	3834 H	3693
4076 (Ca)	3816	3680
4049	3795 H	3674
4025	3768 H	3667
3989	3757	3658
3968 H	3746 H	3653
3955 (Ca)	3730 H	3635 (Ca ?).]
3933 K	3718 H	

75. The Corona and its Spectrum.

In the eclipse of 1868, the observers were too much occupied with the spectroscopic investigation of the prominences to pay adequate attention to the examination of the corona. The few observations that were obtained agree as to the sudden disappearance of all the dark lines on the commencement of totality, and to the fact that the corona gave only a *faint, continuous* spectrum. Tennant admits that faint lines may have been present which he was unable to perceive, because, to ensure himself from disappointment, he had employed a rather wide opening of the slit.

The eclipse of 1869 furnished many valuable data con-

cerning the corona, in full confirmation of the previous observations that the spectrum is free from dark lines.

Pickering, Harkness, Young, and others, are agreed that, with the extinction of the last rays of the sun, all the Fraunhofer lines disappeared from the spectrum. The small instruments employed by Pickering and Harkness, in which the field of view was large, exhibited a spectrum obtained at once from the corona, the prominences, and the neighbouring sky. During totality a faint, continuous spectrum was visible, free from dark lines, but crossed by *two* or *three bright* lines.

Young, with his spectroscope of five prisms (Fig. 171), observed the three bright lines in the spectrum of the corona, given in Plate V., No. 2, and drawn according to Kirchhoff's millimetre scale introduced above. These lines were 1250 ± 20, 1350 ± 20, and 1474.

The wave-length of the line 1474 is, according to Ångström, 0·00053159 millimetre. Its coincidence with one of the lines of iron is only apparent, and results from the small dispersive power of the spectroscope employed. By the use of a powerful spectroscope, this line was discovered by Young, in 1876, to be double. The most refrangible of the two was nebulous, while the other was sharply defined. The former is the true corona line; the other belongs to the vapour of iron. Fig. 174 gives a portion of the spectrum near the line in question, after a drawing by Young.

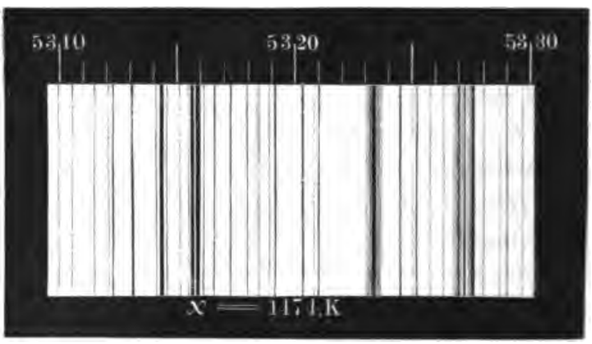
To what substance the corona line is due is at present unknown. Of the five lines observed by Winlock in the spectrum of the aurora one appeared to be near the line 1474 (K.) (Plate V., No. 3), and was supposed by Young to be identical with the corona line, but he was afterwards convinced that the lines were wholly unconnected.

In examining spectroscopically the corona during the

eclipse of the 22nd December, 1871, Respighi and Lockyer adopted the method, first suggested by Secchi in 1868, of viewing the eclipse with a direct-vision system of prisms without slit or collimator. Respighi employed an object-glass prism of small refracting angle; Lockyer made use of a system of five prisms in the eye-piece. By this method of observation an annular image, coloured according to the colours of the corona lines, ought to appear, and this proved to be the case.

But in addition to the distinct and brilliant images, there

FIG. 174.



The Corona Line, 1474 K, and its Neighbour, after Young.

appeared traces of several others, corresponding, in all probability, to familiar corona lines, all of which stood out against a faint and confused background spectrum. After careful examination of the phenomena, Secchi comes to the following conclusions: 1. The coloured images were not all of equal height; the green of the corona appeared to be the highest; the four images of the prominences at C, D_3, F, and *h* were similar in form, but diminished in size, in the direction from C to F, in a similar manner to the behaviour of the bright lines of the prominences. 2. The green image of the inner annular corona was per-

fectly uniform, and was the most distinct; it was best defined at its upper part, although the light was less intense there than at the base. Its form was apparently circular, and extended as far as from six to seven minutes from the sun's limb. 3. The corona image was also visible in the red at C, but somewhat diffused and not so bright as the green line near 1474; even in the blue near F and *h* traces of images were visible. 4. The coloured images appeared against a faintly-coloured background; if, therefore, the light from the corona contains other lines than the green 1474, they must be very much fainter.

In observing the same eclipse by the ordinary method, Janssen noticed a faint, continuous spectrum, and in addition to the bright green line, several pale ones, among which he identified D.

In the solar eclipse of the 29th of July, 1878, Professor Brackett, stationed at Denver, under the direction of Professor Young, was unable to see a trace of any coloured corona image. Young employed a fluorescent eyepiece in order to observe the ultra-violet spectrum. Before the eclipse numerous dark lines were visible, but during the darkness no trace of bright lines could be discovered. No more definite results were yielded by photography, for the most carefully prepared sensitive plates applied by Draper, Lockyer, and others, to spectroscopes, from which the slit had been removed, received only the impression of a faint continuous spectrum in the ultra-violet without rings or marks of any kind. Apparently there were no lines present that could be seen or photographed. Professor Rockwood found the spectrum of the corona continuous and tolerably bright, but not a trace of bright lines could be seen. Professor Eastman endeavoured to ascertain the height to which the continuous spectrum extended, and found that although the corona varied in intensity at dif-

ferent parts of the sun's limb, the spectrum disappeared at nearly the same distance from the sun's edge at every point. Professor Barker, stationed at Rawlins (Wyoming), searched in vain for any bright lines; the appearance presented to him was that of a bright continuous spectrum. Upon contracting the slit the Fraunhofer lines became visible, which upon further scrutiny were found to extend only as far as corresponded with the image of the corona. They gradually faded from the base of the spectrum upwards, and seemed to terminate at the edge where the continuous spectrum began.

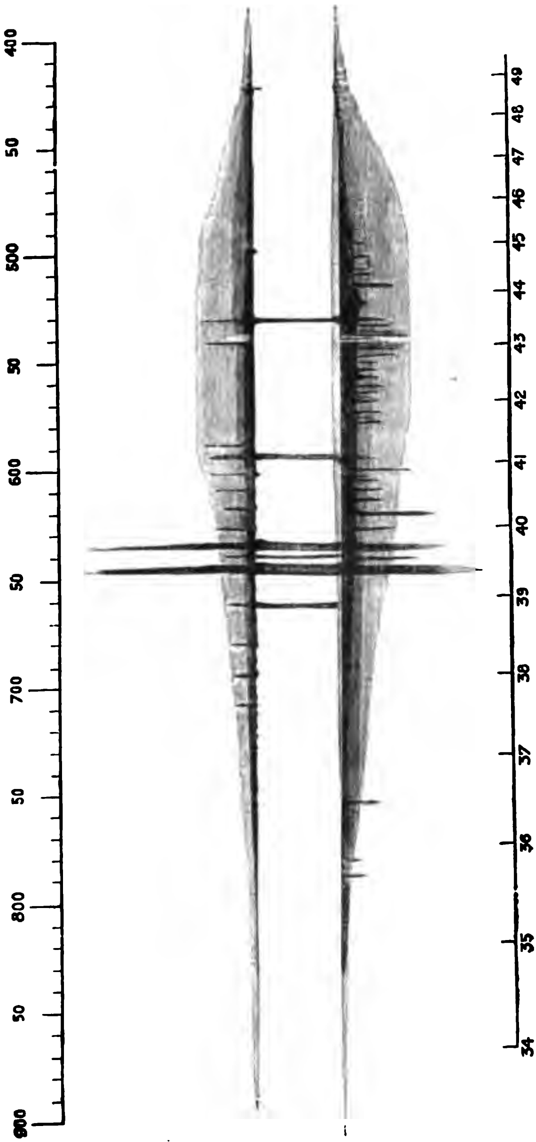
[In the eclipse of 1882, the same photograph which gave the longest list of prominence lines also gave the bright lines to be found in the corona. The following is a list:—

4526	4212
4501 double ?	4195
4473	4179
4442	4173
4414	4168
4401 short	4101 h
4395	4085
4370 short and winged	4067
4340 Hy	4057
4289	4044
4267	4015 comparatively strong
4252	3992
4241	3948
4224	

The slitless spectroscope also showed that in the corona is a mass of 1474 (Kirchhoff) stuff, and also the gas which gives out D_3, as rings corresponding to these wave-lengths were found on the negative (Fig. 175).

Abney and Schuster further found that part of the coronal light was reflected sunlight, as the Fraunhofer lines were photographed, feebly it is true, but still quite visibly, in the portion of the spectrum near G, which is the part of the

Fig. 175.



Mixed Spectrum of Corona and a Prominence.

spectrum which most readily impresses the photographic plate.

Quite recently Dr. Huggins has shown that the corona may be photographed in full sunlight. Observing that the coronal spectrum was most intense at one particular region, he placed solutions of permanganate of potash, or coloured violet glasses, in front of a sensitive plate, on which was formed an image from a *reflector*. By carefully timing the exposure of the plate he was able to make the light of the corona impress itself more than the light coming from the intervening skylight, and thus obtained images of the corona. Compared with the eclipse photographs of 1882, the plates secured by Huggins, about the same time, showed the same coronal form. Huggins subsequently modified his process, concluding that the part of the spectrum near H might give the best results. On the recommendation of Abney he tried chloride of silver, as being particularly sensitive to that region to receive the image, and with these he obtained marked success. Photographs taken in the Caroline Islands during the eclipse of 1883, and Dr. Huggins's photographs taken with an uneclipsed sun, which were taken at very nearly the same time, again showed the same general features. Huggins has employed other sensitive salts for the purpose, and succeeded with most. At the time we write photographs are being taken under the direction of a committee of the Royal Society, at a high elevation, to further test Huggins's method].

It has been thought that the inner bright circle of coronal light closely surrounding the moon's limb belonged to the solar body, but that the rays streaming from the luminous ring were merely the rays of the sun reflected from the dark and uneven surface of the moon, and brought by refraction into the earth's atmosphere. It would, however, be incorrect to regard the radiation of the corona as an

optical phenomenon, for a comparison of the photographic pictures shows that with the moon's advance, the corona became more covered at the eastern edge of the sun, and more exposed at the western edge; in no way participating in the moon's motion, but continuing stationary during the eclipse. That the corona therefore belongs to the sun admits of no doubt, but this seems only to make its nature the more obscure. From the observations of solar eclipses, including that of 1878, it seems tolerably certain that the causes which give to the spots a periodicity of eleven years exert a similar influence upon the corona.

In discussing the results obtained from observations of the eclipse of the 29th of July, 1878, Schuster was led to the somewhat bold conclusion that inasmuch as the appearance of a continuous spectrum indicates the presence of solid or liquid particles, they may be supposed to consist of cosmical meteors. These may be conceived of as a continuous shower falling into the sun from every direction, and while shining by reflected solar light also give out light of their own in consequence of the extreme heat to which they are subjected. Young also deems it probable that while the gaseous constituents of the corona belong to the sun, the solid portion—the corona dust or nebula—is of foreign and probably meteoric origin. In the present state of our knowledge on this branch of science, the question as to the nature of the corona still remains unanswered; the solution of this problem must be reserved till, by the careful observation of future total eclipses, fresh data shall be collected, which may either confirm the theories already advanced, or suggest new ones in their stead.

76. Method of observing the Spectra of the Prominences and Chromosphere in Sunshine.

In observing the solar eclipse of 18th August, 1868, Janssen was surprised by the remarkable brilliancy of the prominence-lines, and exclaimed as the sun reappeared and the prominences faded away, "Je reverrai ces lignes là en dehors des éclipses!" Clouds prevented him carrying out his intention on that day, but on the 19th of August he was up by daybreak to await the rising of the sun, and scarcely had the orb of day risen in full splendour above the horizon than he succeeded in seeing the spectrum of the prominences. The phenomena of the previous day had completely changed their character: the distribution of the masses of gas round the sun's edge was entirely different, and of the great prominence scarcely a trace remained. For seventeen consecutive days Janssen continued to observe and make drawings of the prominences, by which it was proved that these gaseous masses changed their form and position with extraordinary rapidity. Janssen's paper communicating his discovery to the French Minister of Education is dated the 19th of September, 1868.

The achievement of Janssen was based upon principles already placed before the scientific world in a paper communicated to the Royal Society by Lockyer, in 1866. Shortly after Janssen's announcement, Lockyer, by the use of increased dispersive power, was able to obtain the spectrum of a solar prominence (Fig. 170, No. 6), the lines of which are thus described: 1. Absolutely coincident with C; 2. Nearly coincident with F; 3. Near D. This third line near D, always a very fine line, is more refrangible than the most refrangible of the two D-lines (that is to say, it lies nearer to the green), and is designated D_3.

The possibility of observing the lines of the prominences in bright sunshine lies in the difference between the continuous spectrum of the sun and the line spectrum of the prominences. If the two spectra be formed in the same spectroscope in juxtaposition, the line spectrum will be usually overpowered by the brightness of the continuous spectrum. But if, by an increase in the number of prisms, the spectra be extended, the light of the continuous spectrum may be reduced to almost any amount, while the lines of the prominence spectrum will only become further separated without suffering any perceptible loss of light. Thus in a spectroscope of highly dispersive power, the prominence lines retain their brightness so as to be observed even on the disc of the sun. The greater, therefore, the dispersive power of the instrument, the brighter will the coloured lines of the prominences appear to be.

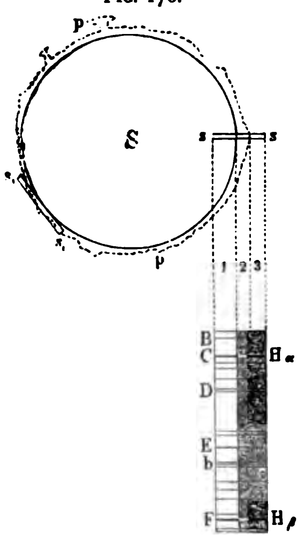
It was on these considerations that Lockyer based his plan of observing the spectra of the prominences in full sunshine. The telescope employed was an excellent refractor of 6¼ inches aperture, and 98½ inches focal length, driven by clock-work, and the spectroscope consisted of seven prisms of dense flint glass* of 45° each, with a refracting angle of more than 300°. When greater power was needed, an eighth prism of 60° was added, and occasionally a direct-vision spectroscope was introduced into the telescope.

Fig. 176, in connection with Fig. 172, will explain more clearly this method of observing the prominences. S represents the solar image as formed by the object-glass of the telescope, *p p* the image of the prominences, invisible owing to the overpowering solar light. The slit *s s* is placed perpendicularly to the sun's limb, and is therefore in the direction of the sun's radius, so that one half falls on the

* The glass had a specific gravity of 3·91, a refractive index of 1·665, and a dispersive power of 0·0752.

sun's disc, while the other half extends beyond it on to the surrounding envelope of glowing hydrogen (the prominences). In spectrum 1, which is still bright, though very much weakened by the great dispersion of the light, the Fraunhofer lines are very strongly marked. The other half of the field of view contains the spectrum of the air 2, 3, which is extremely faint, and which by a sufficient increase in the number of prisms may be very nearly extinguished. The spectrum 2 of the prominence stratum *p p* appears upon this spectrum in immediate contact with the spectrum 1 of the sun's disc, and it has been found by observation that spectrum 2 consists of several *bright* lines, among which the hydrogen lines are at all times particularly brilliant, of which Hα (red) forms the exact prolongation of C, Hβ (greenish-blue) the equally accurate prolongation of F, and Hγ (blue) less refrangible than G (not represented in the drawing); there is also to be seen the line, as yet unknown, D_3, immediately following the sodium line D_2.

FIG. 176.

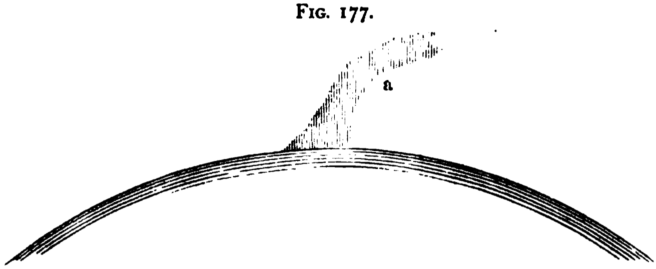


Method of Observing the Prominences.

If the spectroscope be directed to the extreme edge of the sun, and the slit carried round the sun, the spectrum of the prominences will be immediately recognized; and, as the lines appear only where an accumulation of hydrogen is present, from the greater or less length of these bright lines a drawing of the form and position of the prominences round the sun may be made with almost the same accuracy as during an eclipse. A prominence thus observed and sketched

by Lockyer is shown in Fig. 177. As the length of the bright lines depends upon the height of the prominence, and these lines appear only when the light of the luminous gas falls into the slit, attention need only be directed to one of these bright lines, the bluish-green F-line ($H\beta$) for instance, in order to determine the form of a prominence. If such a line be observed to be of some length, a prominence is then in view; and if the slit be turned slowly to the right and to the left, the line will lengthen or shorten according as the prominence is higher or lower; it will also appear interrupted, divided, or, as at the point *a*, isolated

FIG. 177.



Sketch of a Prominence by means of its Spectrum Lines.

from the solar spectrum, according as the prominence itself is interrupted or separated from the sun's limb.

Plate V., No. 4, represents the spectrum of the sun, and that of the prominences as they usually appear in a large telespectroscope with a radial slit. In the latter spectrum, besides the four bright lines of hydrogen, other bright lines are generally visible in correspondence with the Fraunhofer lines; among these, the yellow line D_3 beyond D is usually present, and frequently a green line, due to iron, 1474 (Kirchhoff), besides the three magnesium lines *b*, and, according to an observation by Rayet, the two sodium lines D_1 and D_2. From the circumstance of the spectrum of the prominences, as well as that of the gaseous stratum *p p* immediately surrounding the sun, being composed of coloured

lines, Lockyer has given to this gaseous envelope the name of *chromosphere.*

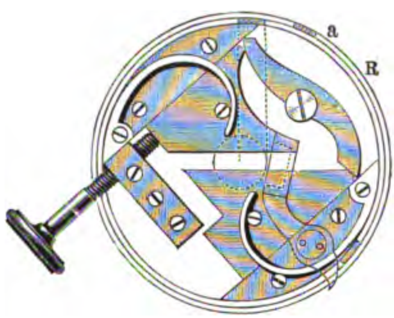
Upon the arrival of the news of Janssen's discovery, Secchi began a series of spectrum investigations of the prominences. He employed a spectroscope of two flint-glass prisms of high dispersive power, capable of showing the fine Fraunhofer lines between B and A, and placed it in combination with an excellent equatorial. When the slit was carried completely round the disc of the sun, he observed that the bright line C (red) was everywhere visible. With the slit perpendicular to the sun's limb, this line was always from 10″ to 15″ in length, excepting in a zone of 45° on each side of the equator, where the solar spots and faculæ are known to abound, in which region this line was four times its ordinary length. In many places it was separated from the sun's limb, when, if the slit was placed at a tangent to the limb, this bright line always crossed the entire spectrum, but when the slit was removed from the sun's limb, it sometimes appeared separated in detached pieces.

This proves that the stratum of glowing gas—the chromosphere—surrounding the sun is really continuous, though distributed very unevenly. Where a bright line attains the height of 60″ or more in the spectrum, it proclaims the existence of a prominence, and where a bright line is broken into fragments, it is an indication of the presence of isolated masses of glowing gas—of solar clouds at a considerable height above the sun's surface.

Direct-vision spectroscopes, of even moderate dispersive power, may be used with advantage for the observation of the prominences, if introduced into the telescope in place of the eye-piece. Instead of examining the direct image of the sun as formed by the object-glass, the slit may be directed on to a magnified image obtained by drawing out the eye-piece of the telescope.

An ingenious arrangement for an adjustable slit is shown in Fig. 178. It consists principally of two steel plates, travelling upon edges of steel, which, by the revolution of a *single* screw, can be made to separate in unison from a central point, and by the action of a spring be brought to approach again. In this way, the width of the slit may be increased to nearly a quarter of an inch. By turning the outer ring R, the comparison prism, which receives its light through the opening at *a*, is drawn aside, and the full light from the object-glass allowed to fall upon the whole length of the slit.

FIG. 178.



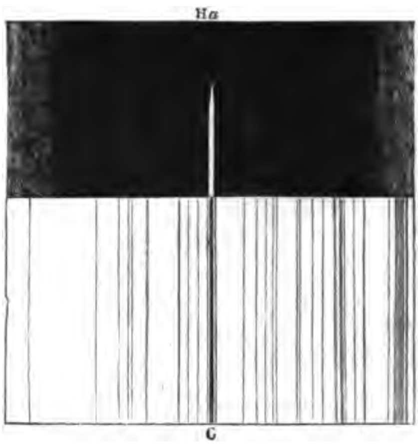
Arrangement of the Slit in the Spectroscope.

Figs. 179, 180, and 181 represent, after Lockyer's drawings, those portions of the spectrum which include one of the chromosphere and prominence lines. Fig. 179 shows the C-line, with the hydrogen line H*a*, of the chromosphere, equally broad, and somewhat pointed at its termination. Fig. 181 exhibits the F-line, and above it the hydrogen line Hβ of the chromosphere. This line is spread out at the base, and terminates above in an arrow-shaped point; the line H*a*, on the contrary, remains, as a rule, of the same width throughout as the C-line. Fig. 180 represents that portion of the solar spectrum beyond the double sodium line

D, where, about midway between two very fine dark lines, the yet unknown line D_3 is situated in the spectrum of the chromosphere.

While the red line H*α* is always brilliant and easily seen, the greenish-blue line H*β*, though bright, is fainter and frequently also much shorter than H*α*. The F-line, as well as its corresponding line H*β*, is subject to a variety of changes, such as becoming inflated, bent, widened, twisted, and broken up.

FIG. 179.



The Spectrum of the Sun's Disc (below) and that of the Chromosphere (above) near the C-line.

Besides these bright lines in the spectra of the prominences and the chromosphere, there appear from time to time many other bright lines, very marked and brilliant, among which are two lines in the red, one between B and C, but nearer to C,—estimated by Respighi to be removed from C by 0·041 of the distance between C and B,—and the other less refrangible between B and *a*, and distant from *a* 0·036 of the space between B and *a*. Neither of these lines correspond with the lines of any as yet known substance ; they are not unfrequently seen with very great brilliancy in the higher

part of the prominences. Very frequently, too, there is to be seen another line in the green between E and F (Fig. 170, Nos. 3, 5, 8), as also the line 1474 (K.), the magnesium lines, etc.

The third hydrogen line Hγ (blue) near G (Fig. 170, No. 2), No. 2796 (K.), No. 2798·6 (Ångström), appears very brilliant under favourable circumstances; and when the air is transparent and free from vapour, and a high

FIG. 180.

The Spectrum of the Sun's Disc (below) and that of the Chromosphere (above) near the D-line.

prominence is present, there is also seen the fourth hydrogen line Hδ (blue, 3370·1 K.), which coincides precisely with the dark line marked *h* by Ångström, of a wave-length of 0·00041011 of a millimetre; this line was seen by Rayet with great distinctness on the 30th of April and on the 1st and 20th of May, 1869.*

The remarkable yellow line D_3 (Fig. 180) is seen as constantly in every part of the circumference of the sun's

* [It is a line which is often to be seen.]

disc as the hydrogen lines; the luminous gas to which it is due must therefore, like hydrogen, form a constituent of the chromosphere. Lockyer has been unable to find any corresponding dark line in the solar spectrum for this line, notwithstanding the most careful micrometric measurements, and the most painstaking comparisons with the maps of Kirchhoff and Gassiot. It was, however, identified by Vogel of the Bothkamp Observatory, on the 29th of October,

FIG. 181.

The Spectrum of the Sun's Disc (below) and that of the Chromosphere (above) near the F-line.

1871, and by Tietjen of Berlin, with one of the most prominent of the fine dark lines which appear in the neighbourhood of the D-line when the sun is low in the horizon. As the result of numerous measurements, the wave-length of D_3 is found to be 587·38 millionths of a millimetre. Fig. 182 shows the numerous atmospheric lines in the neighbourhood of D, which have been observed by Vogel to make their appearance as the sun nears the horizon. The lower spectrum is a portion of that of the sun's limb, the upper one the corresponding portion of that of our atmosphere. The

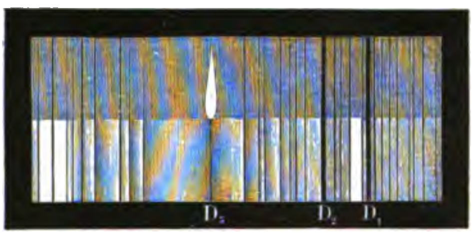
two prominent lines are D_1 and D_2; the bright line in the upper part is the line D_3 of the chromosphere.

A series of observations upon this line has also been instituted by Lockyer, who in conjunction with Frankland had previously ascertained, by comparisons with the spectrum given by a tube filled with hydrogen, that it could not be attributed to hydrogen gas. The results obtained were as follows:

1. With the slit tangential to the sun's limb, the line D_3 appeared bright at the lower part of the chromosphere, while in the same field of view the C-line was dark.

2. In a prominence over a spot on the sun's disc the lines

FIG. 182.



Surroundings of the D-lines, after Vogel.

C and F were bright, while the yellow line D_3 was invisible.

3. In a prominence which burst forth from the sun under high pressure the motion indicated by change of the wave-length was less for the line D_3 than for either C or F.

4. In one case the C-line appeared long and continuous, while the line D_3, though of equal length, was broken and interrupted.

It follows from this that the line D_3 is certainly not occasioned by hydrogen gas,* and its source is therefore at present still undiscovered. It is usual to designate it a helium line.

* [This can hardly be said to be settled in the light of the newer experiments made by Lockyer and De la Rue which we believe have been recently made.]

The reversal of the sodium lines D_1 and D_2 (*vide* Plate V., No. 4) has been observed by Lockyer, and subsequently also by Rayet, in the spectrum of the chromosphere; that is to say, they have been seen as bright lines. With a tangential slit, Rayet saw both these lines dark upon the sun's limb. In observing a magnificent prominence 3′ high, which appeared to rest upon the sun's limb, both these lines were somewhat dark at the base; when nearly two-thirds from the base they had entirely disappeared, but by a slight displacement of the slit they were again discovered in the form of bright yellow lines, and at the summit of the prominence they were again dark.

The magnesium lines b_1, b_2, b_4, as also the line b_3, composed of lines of nickel and iron, are seen not unfrequently as bright lines in the spectrum of the chromosphere, but almost always as very short lines, which seem to show that the vapour of magnesium does not rise to any great height in the chromosphere. When these bright lines are visible, the first three, b_1, b_2, b_3, appear of about equal length, while the fourth line, b_4, is much shorter (Plate V., No. 4). It has been found by Lockyer and Frankland that a similar phenomenon is to be noticed in the spectrum of terrestrial magnesium when formed by the passage of the electric spark through the air between electrodes of this metal, and the poles too far separated to allow of the spectrum extending from one pole to the other, but each pole surrounded by a luminous vapour of magnesium. In observing at a short distance the spectrum of this luminous gaseous envelope, the most refrangible of the three magnesium lines that made their appearance was always the shortest, and shorter still were several other lines which have not been observed as yet in the spectrum of the chromosphere. Of the many iron lines occurring as dark lines in the solar spectrum, only a few appear as bright lines in the spectrum of the chromosphere; among these, the one

most frequently observed is the well-known line 1474,* which shows itself as a short green line. Young gives the following catalogue of all the lines that are constantly visible in the spectrum of the chromosphere, together with their respective wave-lengths according to Ångström :—

1. 7055 ± . . .	Element unknown.
2. 6561·8 C . .	Hydrogen (Hα).
3. 5874·9 D_3 . .	Element unknown, termed Helium by Frankland.
4. 5315·9 . . .	Corona line, element unknown.
5. 4860·6 F . .	Hydrogen (Hβ).
6. 4471·2 *f* . .	Cerium (?).
7. 4340·1 near G .	Hydrogen (Hγ).
8. 4101·2 *h* . .	,, (Hδ).
9. 3969 ? . .	Element unknown.
10. 3967·9 H . .	Possibly hydrogen.
11. 3932·8 K or H_2 .	,, ,,

These lines are invariably present in the spectrum of the chromosphere; a much larger number are occasionally seen in addition.

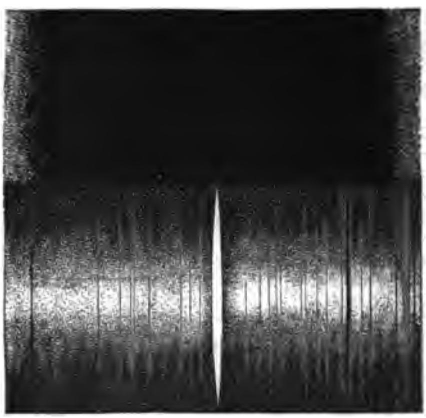
At certain times, when powerful eruptions from the interior of the sun extend into and even beyond the chromosphere, the spectrum of the latter becomes very complicated. Phenomena of this kind have been frequently observed by Lockyer with a *tangential* slit. This position offers the advantage of viewing at one time a much larger extent of the sun's limb, or chromosphere, than can be obtained by a slit placed radially, although the latter position is advantageous when the object of the observer is to watch the changes occurring in the chromosphere, or to observe

* [Young has shown that the line in the solar spectrum supposed to be coincident with the 1474 line, and which is marked as an iron line, is really a double line, only one component of which is due to iron. The 1474 line of the chromosphere, he has shown, is not coincident with this component. Rowland has more recently photographed this line in the solar spectrum as a double line.]

especially the form and height of the prominences. When the slit is placed tangentially upon the sun's limb, so that portions of the sun and chromosphere are visible at the same time to an equal height in the slit, the spectra of the sun and chromosphere are no longer seen side by side, but are partially superposed, the one obscuring the other.

Fig. 183, from a drawing by Lockyer, shows the C-line during the observation of a prominence; the dark C-line was

FIG. 183.



C

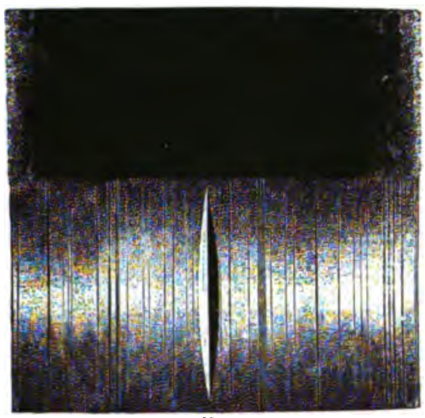
Covering of the Dark C-line with $H\alpha$.

completely annihilated, and replaced by a bright band. The F-line, as shown in Fig. 184, was differently affected. In the spectrum of the light emitted from the extreme edge of the sun, the bright line $H\beta$ appears to be of greater refrangibility than the dark F-line itself, but at a short distance from the sun's limb the dark F-line in the spectrum of a prominence was completely replaced by the corresponding bright line of hydrogen. Many other lines besides those of hydrogen appear bright under similar circumstances in the spectrum of the chromosphere, and on the 17th of April, 1870,

hundreds of such bright or reversed Fraunhofer lines were observed by Lockyer at a spot in the chromosphere where a prominence was situated. The complications in the spectrum of the chromosphere were most remarkable in the regions more refrangible than C, and in those extending from the line E to beyond *b*, and as far as the neighbourhood of F.

The following table has been made by Young of the lines

FIG. 184.



F

Partial Covering of the Dark F-line with $H\beta$.

frequently appearing in the chromosphere, but not always visible :—

1. 6676·9	Iron.	11. 5183·0 b_1	Magnesium.
2. 6429·9	?	12. 5172·0 b_2	,,
3. 6140·6	Barium.	13. 5168·3 b_3	Iron and Nickel.
4. 5895·0 D_1	Sodium.		
5. 5889·0 D_2	,,	14. 5166·7 b_4	Magnesium.
6. 5361·9	Iron.	15. 5017·6	Iron and Nickel.
7. 5283·4	?		
8. 5275·0	?	16. 5015·0	?
9. 5233·6	Magnesium.	17. 4933·4	Barium.
10. 5197·0	?	18. 4923·1	Iron.

19. 4921·3 . .	?	26. 4394·6 . .	?
20. 4918·2 . .	Iron.	27. 4245·2 . .	Iron.
21. 4899·3 . .	Barium.	28. 4235·5 . .	,,
22. 4500·3 . .	Titanium.	29. 4233·0 . .	Iron and Calcium.
23. 4490·9 . .	Magnesium.		
24. 4489·4 . .	Magnesium and Iron.	30. 4215·0 . .	Calcium and Strontium.
25. 4468·5 . .	Titanium.	31. 4077·0 . .	Calcium.

In addition to these lines other bright lines were observed in the chromosphere by Young in 1872, while stationed at Sherman (Wyoming), at an elevation of 8280 feet, by the use of a 9-inch refractor and an automatic spectroscope of twelve prisms. His catalogue includes in all 273 of such lines.

Among the most remarkable phenomena observable in the bright lines of hydrogen seen in the spectrum of the chromosphere is that of the widening at the base and pointed arrow-like termination of the greenish-blue line $H\beta$, as well as the narrowing to a point of the other bright lines $H\alpha$ and D_3, as represented in Figs. 179, 180, and 181. This pointed termination of the bright lines in the spectrum of the chromosphere indicates that the temperature of the chromosphere decreases as it recedes from the sun, and at the same time, that the density of the hydrogen envelope is greater at the base of the chromosphere than in the higher regions.

The phenomena observed in the C- and F-lines of the hydrogen gas in the chromosphere and prominences do not consist merely in the widening of the lines and their pointed termination, but also frequently in several other changes, such as their becoming swollen out in several places and assuming a twisted appearance, or being broken up into separate pieces,—phenomena which must be regarded as an indication of violent eruptive or stormy action taking place in the interior of the gaseous mass. Lockyer had early made many observations of this kind, and he has recorded

the appearance presented by these lines. An instance is given in Fig. 185, where the F-line of the solar spectrum is accompanied by the corresponding bright prominence-line Hβ, which, in addition to the usual arrow-pointed termination, has assumed the form of a twisted wavy line, the lower part of which spreads out over the sun's disc; the C-line of the same prominence remained in the meanwhile unaffected, being neither spread out at the base nor twisted in form.

FIG. 185.

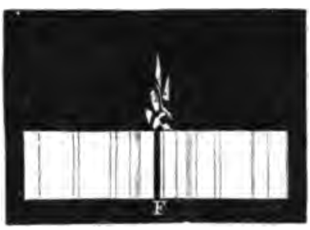
Changes in the Line Hβ after Lockyer.

A similar phenomenon in a very brilliant prominence was noticed by Professor Young on the 19th of April, 1870. The red C-line (Hα) was remarkably bright, so as to admit of its form being observed with a tolerably wide opening of the slit, but in no part was the line either twisted or broken. The F-line (Hβ), on the contrary (Fig. 186), though equally brilliant, was everywhere broken up into pieces, and at the base was three or four times wider than usual.

It will presently be shown in what manner the displacement of a spectrum-line and the phenomena depicted in

Figs. 185 and 186 are connected with the ***motion*** of the luminous gaseous mass to which these lines in the spectroscope owe their origin. When, however, as in these instances, only one of the spectrum lines ($H\beta$) is so affected, and the other line ($H\alpha$) remains unchanged, it is scarcely credible that the cause of this phenomenon is to be found in the eddying motion of the gas whence the light is emitted. Young is of opinion that phenomena of this kind are to be attributed to some local absorption by which a line (colour) which is much spread out by the influence of pressure and temperature is particularly affected. By means of his powerful spectroscope, composed of five prisms, Young was able to watch the above phenomenon for half an hour at a time.

FIG. 186.



Changes in the Line $H\beta$ after Young.

When the atmosphere is exceedingly tranquil in the neighbourhood of a large solar spot, or over a large region in the sun's disc, absorption bands are seen to traverse the whole length 162 of the spectrum (Fig. ~~195~~) crossing at right angles the Fraunhofer lines; they vary in width and in depth of shade according as a pore, a depression, or a completely formed spot is found opposite the corresponding place in the slit. Here and there in the brightest portions of the spectrum there suddenly appears a lozenge-shaped light (Fig. 187, No. 2) in the middle of the absorption line.

Fig. 187, No. 1, shows the dark F-line at the base of a prominence as observed with a tangential slit. In it are to be seen two or three of those lozenge-shaped stripes of light which are due apparently to the greater pressure of the gas; they were more elongated in the direction of the dark line than was the case in the line C. A precisely

similar phenomenon was observed by Young in both the D-lines.

A simple method of illustrating the simultaneous observation of the spectra of the sun and chromosphere has been devised by Lockyer. He noticed that the flame of an ordinary tallow or stearine candle is surrounded by an envelope of sodium vapour not ordinarily visible, but which can be perceived immediately on the application of the spectroscope by the existence of the yellow sodium lines. If the slit of the instrument be moved slowly from the side into the flame, at the spot a little above the place where the wick bends outward, the bright line D will at once appear against a dark background; by a further movement of the slit into the flame itself, a second spectrum, the continuous spectrum of the flame, is formed, and there will be seen side by side, in the same field of view, the two spectra—that of the flame and that of the sodium vapour by which it is enveloped. If the flame be agitated so as to produce a flickering, the bright D-line may be made to pass through similar changes to those observed in the hydrogen lines of the chromosphere.

The following are the results gained concerning the nature of the chromosphere:

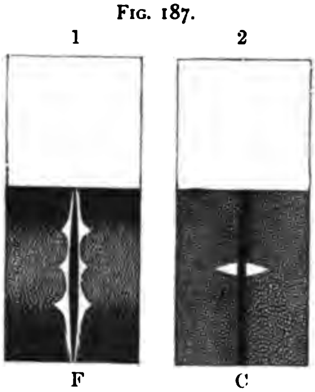
The body of the sun, or its light-giving envelope the photosphere, is completely surrounded by a gaseous envelope in which hydrogen constitutes the chief element, and which is called the chromosphere. Its mean height is between 5,000 and 7,000 miles. The prominences are local accumulations of the chromosphere, and therefore pre-eminently of hydrogen, which break out from time to time in the form of monster eruptions, forcing their way through the photosphere and chromosphere.

The outer edge or upper surface of the chromosphere, according to Secchi, exhibits sometimes an even surface,

but frequently this is broken up into a number of fiery rays or countless small flames of irregular form. In Fig. 188, No. 1 represents the chromosphere when at rest, while No. 2 shows the small flames. According to Secchi's observations, the chromosphere is most frequently rough at the edge, as if set with bristles, especially in the vicinity of the faculæ (Fig. 188, No. 3), or raised into large, wave-like swellings (No. 4), in the process of developing into prominences.

The chromosphere, at its base, merges into the stratum, yielding a continuous spectrum (see p. 269), beneath which again lies the glowing vaporous *photosphere*, containing all substances, the spectrum lines of which appear in the solar spectrum as reversed absorption lines. These substances, among which iron, magnesium, and sodium are the most conspicuous, often break loose and rise to a certain height into the chromosphere and into the base of the prominences.

FIG. 187.



Reversal of the C and F-lines.

77. METHOD OF OBSERVING THE FORM OF THE PROMINENCES IN SUNSHINE.

The possibility of observing the prominences in full sunshine arises, as we have seen, from the specific difference existing between the light of the prominences and that of the body of the sun.

The light of an incandescent solid or liquid body which passes through the slit of a spectroscope will be spread

out by the prism into a band of greater or less length, and form a *continuous* spectrum.

The light of a gaseous or vaporous body will, by the same means, be decomposed into a few—sometimes a very few—bright *lines*.

In the first case, the greater the length of the spectrum, the less will be its intensity in comparison with that of the source of light; in the second case, especially when the spectrum consists only of a couple of lines, the intensity of each line is little less than half that of the light itself.

If, therefore, an equal amount of light from two self-luminous bodies, one solid or liquid and the other gaseous or vaporous, enter the slit of the spectroscope at the same time, the bright lines of the latter will be more brilliant than the corresponding portion of the continuous spectrum.

By increasing the number of prisms, the continuous spectrum may be so elongated, and consequently diminished in intensity, as to be reduced to the verge of invisibility, while the same amount of dispersion produces on a spectrum of lines from glowing gas an increase only in the *distance between the lines*, with scarcely any diminution of their brilliancy.

The reason why the prominences round the sun's limb cannot be made visible merely by screening off the intense light of the sun is owing to the brilliant illumination of the earth's atmosphere, the particles of which scatter so much light as totally to overpower the fainter light of the prominences.

In a total eclipse of the sun this scattered light is so reduced as to allow the larger prominences beyond the limb of the sun to be observed by the unassisted eye. The possibility of reducing the glare of sunlight at any other time without extinguishing the light of the prominences rests on the circumstance already mentioned, that

the light of the sun consists of rays of every colour, and therefore produces in a spectroscope of highly dispersive power a long and faint spectrum, while the light of the prominences, consisting in general of only three or four kinds of rays, remains, even after the greatest dispersive power, still concentrated into the same number of lines ($H\alpha$, $H\beta$, $H\gamma$, D_3).

It was on these principles, first announced by Lockyer, that Janssen succeeded, the day after the eclipse of the 18th August, 1868, in observing the *spectrum* of the prominences in sunshine.

The discovery of this method soon led to the question whether it would not be possible not only to see the lines of the prominences, but also to make their forms visible. We have seen (p. 345, Fig. 177) that by passing the slit over the surface of the prominence, and mapping down the varying height of the line $H\beta$, Lockyer had succeeded in constructing the outline of a prominence, though the prominence itself remained invisible.

It had already occurred, both to Huggins and Zöllner, that by reducing the light sufficiently to allow of the slit being widened, the prominence would be visible when the spectroscope was directed upon one of its spectrum lines. This proved to be the case, and by the use of increased dispersive power, whereby the solar light was diminished, the prominences were clearly seen with a widened slit if one of their spectrum lines was brought into the field of view.

In Fig. 189 will be found some of the prominences thus observed by Zöllner. In Plates VI. and VII. two prominences are represented, in their natural colours, as seen in a large telescope, when the slit of the spectroscope was opened wide and directed on to the red C-line ($H\alpha$). They are characteristic of the two classes, the *eruptive* and the *vaporous*

Pl. VI

Solar Prominence observed by Zöllner.
1869. August 29. Pos. 160

0 10 20 30 40 50 60,000.

English miles

N° 1.
Time. $10^h\ 22^m$

N° 2.
Time $11^h\ 20^m$

Solar Prominence observed by Young
1869 Oct. 7 & 8 Pos 70°-80°

No. 3. Time Oct. 7. 2^h 45^m

No. 4. Time Oct. 8 1^h 50^m 4^h

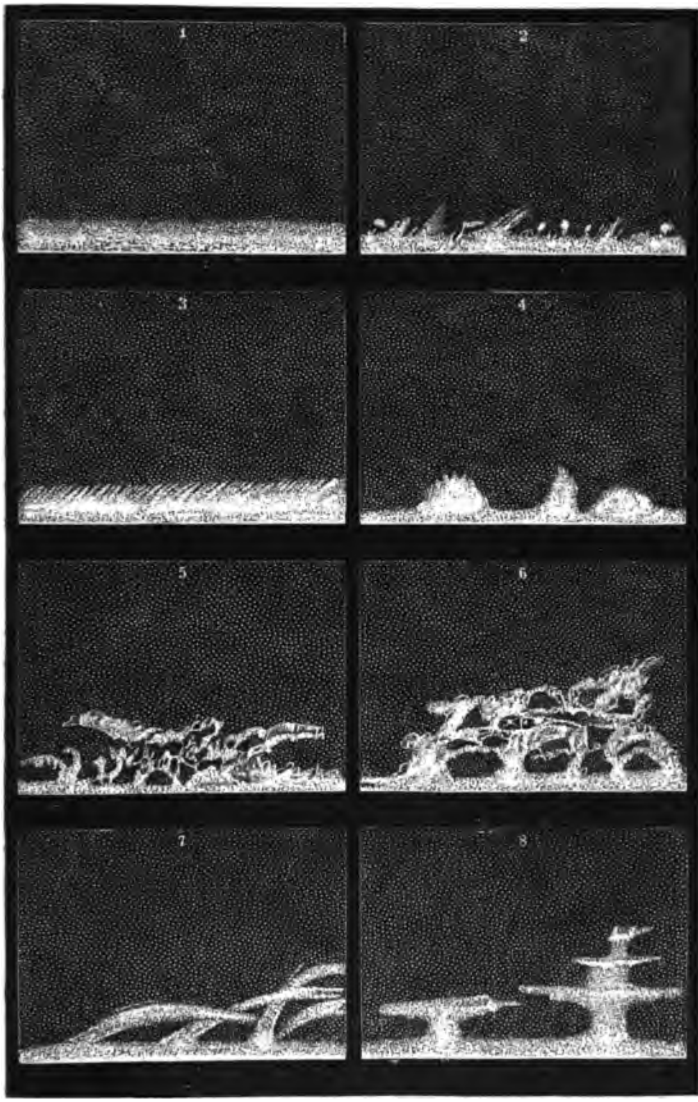


Fig. 188.—Chromosphere and Prominences after Secchi.

class, and serve to illustrate the remarkable changes of these forms. The prominence given in Plate VI., Nos. 1 and 2,

was observed and drawn by Professor Zöllner, and is of an eruptive form, with a decided rotatory movement. The prominence represented in Plate VII., Nos. 3 and 4, is one observed by Professor Young, and is of a cloud-like character. By means of the accompanying scale, their height can be ascertained.

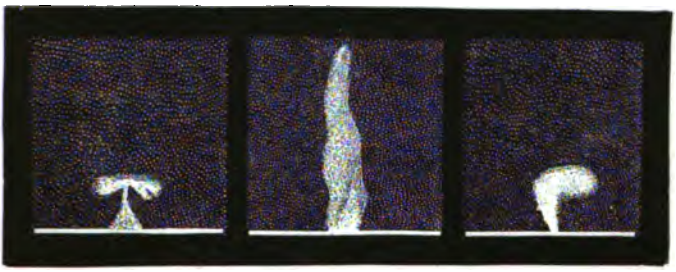
It is in most cases a matter of indifference whether the red line ($H\alpha$) or the greenish-blue line ($H\beta$) be selected for this purpose; the requisite width of slit depends mainly upon the condition of the atmosphere. If the spectroscope be fixed upon the C-line, and the slit be so directed on to the limb of the sun that the red line $H\alpha$ appears in the field of view, on widening the slit, the prominence will be seen of a red colour; if, on the contrary, the F-line and the line $H\beta$ be observed, the same form will be visible of a greenish-blue colour.

It may not perhaps be superfluous to mention that even with the smallest opening of the slit a very considerable portion of the sun's surface is included in the field of view. If this opening be only $\frac{1}{250}$ of an inch, and the image of the sun nearly an inch in diameter, the space on the sun's surface included would be of about 3,300 miles in extent.

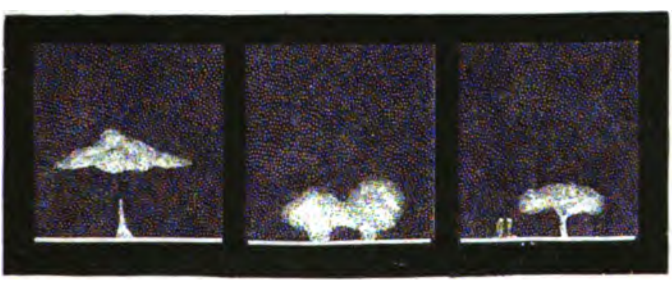
If a diffraction grating is to be employed, the arrangement of the instrument will be as in Fig. 190. S O is the collimator, and S the slit, which must be placed in the focus of the refractor to which the spectroscope is attached. F is the telescope, which may be permanently fixed to the collimator, as the only motion necessary is that of the mirror *m*, upon which is the grating *g g*. If the grating be made to revolve round a centre perpendicular to the plane of the drawing, the spectra of various orders will be formed in the telescope F. Owing to the overlapping of the spectra, by which the red end of the spectrum of the second order is projected upon the blue portion of the spectrum of the third

order, it is sometimes necessary to separate the spectra. This may be accomplished, according to the suggestion of Sir John Herschel, by introducing between the grating *m* and

FIG. 189.



1st July, 3 hrs. 20 min., S.W. Margin, Height = 38 sec. — 1st July, 3 hrs. 45 min., N.E. Margin, Height = c. 120 sec. — 1st July, 6 hrs. 45 min. Pos. Angle = 76°, Height = 35 to 40 sec.



2nd July, 11 hrs. 35 min., Pos. Angle = 278°, Height = c. 35 min. — 4th July, 9 hrs. 0 min., S.E. Margin, Height = c. 40 sec. — 4th July, 6 hrs. 30 min. N.W. Margin, Height = 35 sec.

Solar Prominences observed by Zöllner.

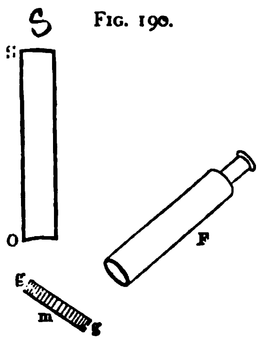
the telescope F a single prism of which the plane of dispersion shall be perpendicular to that of the grating.

It was with a diffraction instrument of this description, the construction of which is given in Figs. 190 and 191, that

Young prosecuted his numerous and important observations at Princeton.*

Through a small telescope the details of these forms are less clearly visible. But an observer furnished with a telescope of four inches aperture, in combination with a spectroscope whose dispersive power equals that of five or six ordinary prisms, is amply provided for the scrutiny of both chromosphere and prominences. How far the slit must be opened in order to obtain the sharpest image of the prominences must always be a matter of experiment. If the slit be opened too wide, the image of the prominence gradually loses itself in the bright spectrum of the atmosphere.

FIG. 190.



Construction of the Diffraction Spectroscope.

Among the observers who have been most actively engaged hitherto in the investigation of the prominences may be mentioned Lockyer, Tacchini, Respighi, Secchi, Vogel, and Young.

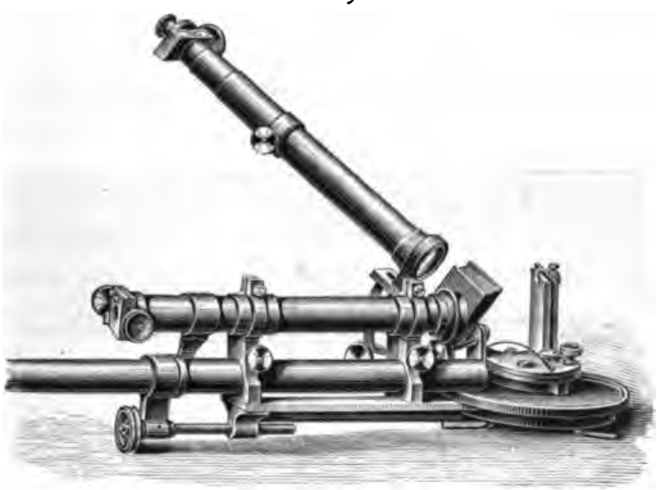
By aid of his powerful instrument, Young has made valuable

* In employing a diffraction spectrum for observing the prominences, Young was but following the example of Secchi and Vogel. It offers the advantage of an increase in the dispersive power of the instrument through the adoption of a higher order of spectrum, without an increase in the size of the apparatus.

The diffraction spectroscope, however, has this disadvantage, that on widening the slit the object appears slightly distorted, either compressed or expanded in a direction at right angles to the position of the slit. When the grating surface is more inclined with respect to the telescope than to the collimator, the prominences upon the slit, being tangential to the sun's limb, appear slightly compressed; when the inclination is reversed the prominences appear elongated. This deviation from the normal height may easily be rectified by calculation. Thus if h be the apparent height, H the true height, and k the

records of the forms of the prominences and the changes to which they are subject. On the 17th of September, 1869, he saw an extended chain of prominences between + 80° and + 110° position angle, a drawing of which is given in Fig. 192. These enormous masses of flaming gas extended along the sun's limb for a distance of nearly 224,000 miles, and attained a height of 50″, or 23,000 miles; the points of greatest brilliancy were at *a* and *b*.

FIG. 191.



Young's Diffraction Spectroscope.

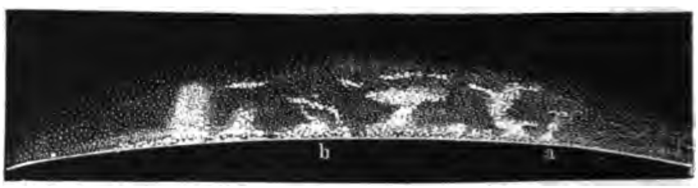
Slight changes in the form of the prominences may be watched almost without intermission with an open slit; great changes as a rule take place only very slowly, or quite imperceptibly. In some cases, however, the change in the form of a prominence is so extraordinary, and occurs with such rapidity, that it can only be ascribed to extremely violent

inclination of the upper surface of the grating with respect to the collimator, and t the inclination with respect to the telescope, then $H = \frac{h \sin t}{\sin k}$.

agitation in the upper portions of the solar atmosphere, compared with which the cyclonic storms occasionally agitating the earth's atmosphere sink into insignificance. The observation of such a solar storm has been thus described by Lockyer :—

"On the 14th of March, 1869, about 9 h. 45 m., with a slit tangential to the sun's limb instead of radial, which was its usual position, I observed a fine dense prominence near the sun's equator, on the eastern limb, in which intense action was evidently taking place. At 10 h. 50 m., when the action was slackening, I opened the slit ; I saw at once that the dense appearance had all disappeared, and cloud-like filaments

FIG. 192.



Young's Observation of a Chain of Prominences.

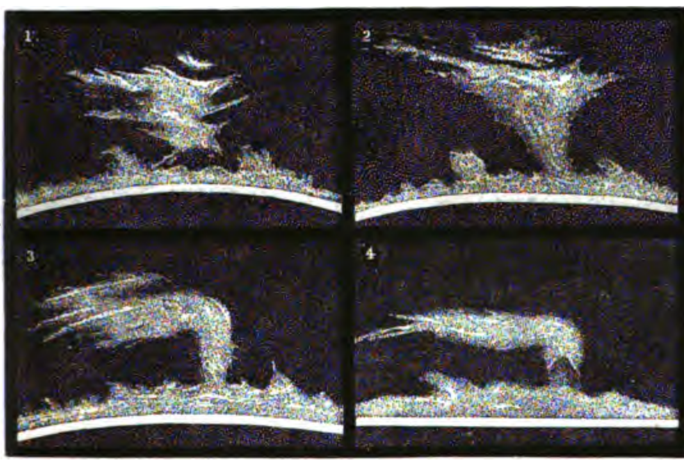
had taken its place. The first sketch, embracing an irregular prominence with a long perfectly straight one, was finished at 11 h. 5 m., the height of the prominence being 1′ 5″, or about 27,000 miles. I left the observatory for a few minutes, and on returning, at 11 h. 15 m., I was astonished to find that part of the straight prominence had entirely disappeared; not even the slightest rack appeared in its place ; whether it was entirely dissipated or whether parts of it had been wafted towards the other part, I do not know, although I think the latter explanation the more probable one, as the other part had increased, which is to be seen clearly in the second sketch that was taken."

The four drawings given in Fig. 193 were made from a brilliant prominence observed by Professor Young on the 7th

of October, 1869. Its height measured 75″. The changes in its form took place with extraordinary rapidity; the four drawings were made at the following epochs, 2 h. 20 m., 2 h. 35 m., 2 h. 55 m., and 3 h. 30 m. A nearly horizontal movement of the various masses of cloud was perceptible in the interior of the prominence.

One of the most remarkable eruptions of prominences that have been yet observed occurred on the 7th of September,

FIG. 193.



Changes in the Form of a Prominence.

1871, and has been described by Young. Between half-past twelve and two o'clock p.m., a kind of explosion took place upon the sun's surface. About noon he had been observing an enormous prominence on the sun's western limb, which had but slightly changed in form since the preceding day, and presented the appearance (Fig. 194) of a cloud composed of horizontal streaks, its lower portion being about 3,200 geographical miles distant from the chromosphere to which it was attached by three or four vertical

pillars of great brilliance. It measured in length 3′ 45″, and nearly 2′ to its greatest limit in height; therefore it had an extension in length along the sun's limb of about 21,700 geographical miles, and reached to a height of about 11,700.

After an absence of half-an-hour, at 12 h. 55 m., he was amazed to find that the whole prominence, by a violent eruption, had been torn into shreds, and tongues of liquid fire shot up vertically, each one from 10 to 30″ long, and from 2 to 3″ in breadth. They appeared most brilliant and were closest together in those parts where the stems had been before, and their motion was very rapid.

FIG. 194.

Prominences observed by Young.

These tongues of flame continued to rise until, at five minutes past one, the highest was more than 43,400 geographical miles above the surface of the sun. Extreme care was taken in the measurement of this height, and the mean of three observations, which agreed very closely, gave for the greatest height 7′ 49″, or about 45,800 geographical miles, a height greater by nearly 3′ than any previously recorded. The speed of the ascending gas was 36 geographical miles in a second, a velocity unprecedented. At a quarter-past one all that remained of the great prominence were a few lumps of luminous matter, together with some bright streaks quite close to the chromosphere, which served to indicate the spot where the magnificent phenomenon had occurred.

During this interval the small mass *a* (Fig. 195) had greatly increased and developed into a surging flame, continually changing in form. At first it seemed to creep upon the sun's surface; later it rose like a pyramid (Fig. 196) to a height of 10,800 geographical miles, the summit of which

dissolved itself in long threads, which bent round in a most remarkable manner. At length it gradually dispersed and completely disappeared at half-past two. This prominence is represented in Figs. 196 and 197, from drawings executed respectively at 1 h. 40 m. and 1 h. 55 m.

On the 28th of September, 1870, Professor Young succeeded for the first time in photographing, in bright sunshine, the prominences on the sun's limb. This he effected by bringing the blue hydrogen line Hγ near G into the middle of the field of the spectroscope, and placing a small photographic camera in connection with the eye-piece of the telescope. As the chemicals employed were those in ordinary use, the requisite time of exposure was 3½ minutes, and the image of the prominence suffered a slight displacement, owing to a want of perfect adjustment in the polar axis. Still the forms of the prominences could be clearly discerned in the photograph, which was half an inch in diameter, and the possibility of photographing them thus proved.

FIG. 195.

Explosion in a Prominence.

In 1874 the attention of Dr. Lohse was directed towards obtaining a photographic image of the chromosphere and prominences, and in his first efforts an absorptive

medium was placed immediately in front of the sensitive plate. In subsequent experiments the image formed by the object-glass was received direct upon a daguerreotype plate. In this way, around the over-exposed image of the sun's disc, Dr. Lohse obtained the impression of a dark ring, a similar result being subsequently obtained by Janssen ; but it remained uncertain whether this ring was in truth the image of the chromosphere, as no prominence was visible.* In the spring of 1880 Lohse adopted an apparatus of another construction, by which the image of the chromosphere was to be built up of a number of images from the slit, and in order to obtain this the whole of the spectrum apparatus was to receive an even motion in front of a stationary camera. A circular motion was adopted, as by this means the slit, when placed in position in the focus of the telescope, was kept directed towards the centre of the sun's disc, by the clock motion of the telescope. The details of the apparatus are shown in Fig. 198. By the object-glass O

FIG. 196.

Prominence observed by Young.

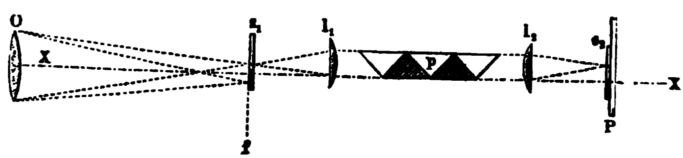
FIG. 197.

Prominence observed by Young.

* [It may be safely said that the ring so obtained was not the chromosphere. This effect is one which is well known in photography, and is dependent on two or three causes which it would be out of place to enter into here.]

of a large telescope, an image of the sun's disc is formed in the focal plane of the violet rays. This image is received upon a blackened disc of metal, upon which a bright circle has been inscribed, the centre of which is coincident with the optical axis of the telescope. Within this circle the image of the sun is concentrically placed and maintained in this position by the action of the clock. In the metallic disc is a small notch in front of the first slit s_1, which may be so reduced by a slide moving radially that no solar light is admitted into the instrument except that of the chromosphere and a minute portion of the sun's outer edge. The concentric position of the sun's image secures the radial position of the slit s_1, which remains undisturbed by the revolution of

FIG. 198.



Lohse's Apparatus for Photographing the Chromosphere.

the instrument around the axis XX. The light emerging from the slit s_1 falls upon the convex lens l_1, which acts as a collimator, and after passing through the direct-vision prism system P, arranged for the violet rays, is received by the lens l_2, which is of the same focal length as l_1. In the focus of the lens l_2 is formed an image of the spectrum of the edge and its neighbourhood, out of which is obliterated, by means of the movable slit s_2, the small portion containing the violet hydrogen line Hγ. Immediately behind the slit s_2 is the sensitive plate P permanently attached to the telescope.

When the apparatus is set in motion, the various parts s_1, l_1, P, l_2, and s_2, which are connected together, travel at a uniform speed round the axis XX, by which means the slit s_2,

to which small strips of leather are attached, is drawn across the dry gelatine plate. In this way there is formed a reversed image of the serrated edge of the sun, in which the prominences are projected towards the centre instead of the circumference. This arrangement is further advantageous inasmuch as the image of the chromosphere, which, in consequence of its revolution, receives a larger exposure than that of the sun's disc, is compressed into a smaller space upon the plate, and therefore exerts a relatively stronger influence upon the sensitive plate.

In Fig. 199, a drawing of the instrument is given. Within

FIG. 199.

Lohse's Rotating Spectroscope.

three cylindrical iron rods, which serve to connect the instrument with the telescope, the tube T revolves with the least possible friction inside the two rings r and r_1. In this tube are contained the five principal parts of the spectroscope, namely, the two slits, the prism system and the two lenses arranged in the order represented in Fig. 198. In Fig. 199 the only parts given of the slit and its mounting are those connected with the sensitive plate, and are designated with the letters s_2. By means of a screw it can be pushed in and withdrawn. The photographic carrier K is introduced into the frame R, the cylindrical portion of which slides without any admission of light into the tube T. Before opening the carrier to introduce the slide, the frame R with the carrier K

must be pushed towards the tube by means of the bar v and the screw w, until it is at the requisite distance between the second lens l_2 and the sensitive plate, and the whole excluded from the light. The carrier is then opened, and the slit s_2 brought towards the sensitive plate by a screw motion. When this is accomplished, and the sun's image is in the field of view, the tube is made to revolve by the turning of an endless screw. This motion, as the drawing indicates, is regulated by hand, but an advantage would doubtless be gained if clockwork were substituted, as from the narrowness of the slit s_1, any slight irregularity in the motion would be perceptible in the image.

Systematic daily investigation of the sun's limb for the observation of prominences was first established at the Observatory of the Campidoglio at Rome, by Respighi, in October, 1869. Fig. 200 shows the method of registration. The observations were made with a direct-vision spectroscope of strong dispersive power attached to a refractor, the slit being carried round the sun's limb in a tangential direction. Regular daily observations have since been instituted at the astrophysical observatory at Potsdam, as well as by Secchi, Tacchini, and Bredichin. The Italian observations are published monthly in the *Memorie della Società degli Spettroscopisti Italiani* (Roma).

To facilitate the search for prominences round the sun's limb Dr. J. Brunn has devised a spectroscope with a curved slit placed eccentrically.* The instrument is attached to a telescope of four inches aperture and five feet focal length, and successfully accomplishes its purpose. The optical part consists of two compound Amici prisms of five prisms each, and two achromatic object-glasses. The eye-piece employed

* [Lockyer and Seabrook had already devised a similar instrument, using a circular slit. The results are described in the Proceedings of the Royal Society.]

is a micrometer eye-piece, composed of two plano-convex lenses.

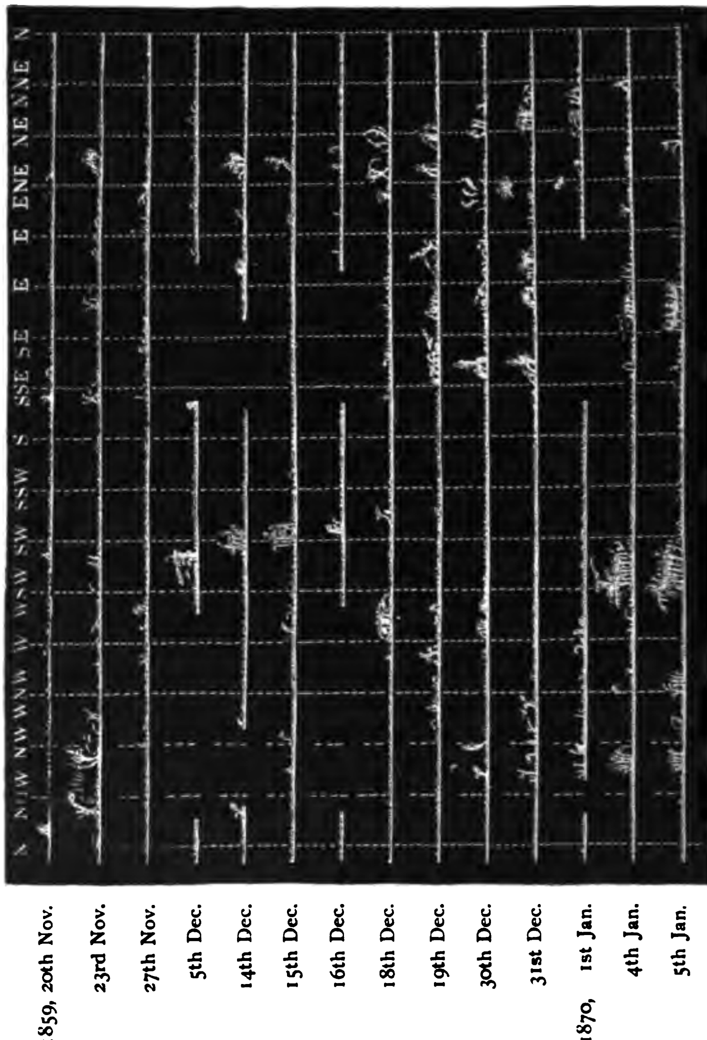


FIG. 200.—Respighi's Observations of the Prominences round the Entire Limb of the Sun.

The regular observation of the prominences has not yet been continued sufficiently long to furnish any definite

results. It has, however, been ascertained from the investigations of Secchi and Tacchini, extending over several years, that the prominences occur least frequently in the polar regions, but gradually increase in frequency up to 30° of latitude, where the maximum occurs, and that a less obvious minimum is to be noticed at the equator. As no large prominences are ever found within 30° of the pole, and their maximum frequency occurs at 30° latitude, it may be inferred, that not only the number, but also the height of the prominences is dependent upon the rotation of the sun and the photospheric currents produced thereby. A comparison of the various periods shows a uniform and continuous change, in which, notwithstanding the limited period of observation, a decided maximum and minimum of intensity is to be noticed, and that the prominences gradually approach towards and then retire from the pole.

These solar eruptions are closely allied to spots and faculæ; but they are of more frequent occurrence, and appear upon almost every portion of the sun's surface while the faculæ are confined to within 50° or 60°, and the spots to about 40° of latitude. This seems to indicate that the conditions necessary for the formation of prominences are readily excited. The faculæ are usually accompanied by prominences which reveal themselves by an increase in brilliancy in the solar surface; for the formation of faculæ, therefore, a necessary condition seems to be a state of intense and violent eruption. Further, the place of the spots is indicated by remarkable eruptions, resulting from an abnormal condition of the chromosphere—eruptions of intense brilliancy, yielding a spectrum of a complex character, from which it would appear that the hydrogen, at a considerable height, is mingled with the glowing vapours of magnesium, iron, sodium, etc. Another characteristic of

these eruptions is their marked intermittence and the entire absence of the numerous lines usually abounding in the chromosphere.

78. Measurement of the Direction and Speed of the Gas-streams in the Sun.

One of the most glorious triumphs of spectrum analysis is the discovery that by accurate measurements of the displacement in the position of the spectrum lines of a star or other source of light it is possible to ascertain whether this source of light is approaching or receding, and at what speed it is travelling.

The principle on which investigations of this kind are founded was suggested by Doppler in 1842, who sought to explain the colours of certain stars by assuming their motion to bear some comparison with that of light, and therefore that the number of ether waves striking the eye in a second would be greater if the star were approaching us, and smaller if it were receding from us than if at rest. Now as violet light produces the greatest number of vibrations in a second, and red light the fewest, it follows that if the star be approaching, its light will be displaced in the direction of the violet, and if it be receding, in the direction of the red. Doppler was right in principle, although the conclusion he then arrived at was untenable. It was not till 1860 that Professor Mach, of Prague, pointed out the true solution of the problem that motion in the source of light can be shown by a displacement of the lines of the spectrum.

The pitch of a musical tone depends, as is well known, upon the number of impulses which the ear receives from the air in a given time. Now as a tone rises in pitch the greater the number of air vibrations which strike the tympanum in a second, so must a sound ascend in tone if we rapidly approach it, and fall in pitch if we recede from it.

The truth of this may be practically proved by listening to the whistle of a railway engine in rapid motion. To an observer standing still, the pitch of the tone rises on the rapid approach of the locomotive, and falls again as the engine travels away, although the note sounded remains unaltered.

As the various tones of sound depend on the rapidity of the air vibrations, so the varieties of colour are regulated by the number of ether vibrations. If, therefore, a luminous object, as, for instance, the glowing hydrogen of a prominence, be *receding* rapidly from us, fewer waves of ether will strike the optic nerve in a second than if it were stationary. If the difference in the number of ether waves be sufficiently great to be perceived by the eye, then each colour of the glowing gas must sink in the scale of the spectrum,—that is to say, incline more towards the red. The individual coloured rays will not then occur in the same position in the spectrum which they would have occupied had the light been stationary; they will be displaced towards the *red*.

The converse takes place when the luminous body is rapidly approaching us: the number of ether vibrations received by the eye is then increased beyond what it would be if the source of light were stationary; individual coloured rays will be found to have changed their position in the spectrum, and suffer a general displacement towards the *violet*.

When it is remembered that the number of ether waves in red light is at least 480 billion and in violet 800 billion in a second, and that moreover the wave-length of the greenish-blue light ($H\beta$), situated at F in the solar spectrum, is only 485 millionth (more precisely 0·00048505) of a millimetre, and that instruments of sufficient delicacy to measure these minute quantities are required for this purpose, there will be little danger of underestimating the extreme

difficulty connected with observations of this displacement in the colours of the spectrum. Indeed, these observations would scarcely be possible were it not that in the dark lines crossing the spectra of the sun and stars, we have fixed positions in the spectrum the wave-length of which may be determined beforehand both for the sun and terrestrial substances, and also for the stars or other sources of light supposed to be at rest.

We shall presently see how Huggins and Secchi have availed themselves of this principle to determine the rate at which a fixed star is approaching or receding from the earth.

Lockyer made use of the same plan for measuring the speed at which the glowing hydrogen gas composing the prominences streams forth from the sun's nucleus, or sinks again when the eruptive force is exhausted. The principle of this method rests on the following considerations.

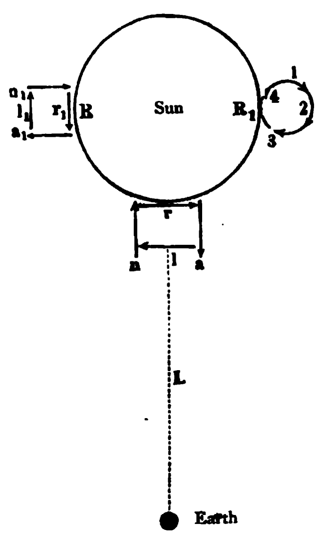
The refrangibility of the greenish-blue light ($H\beta$), which with the red ($H\alpha$) and the blue light ($H\gamma$) is emitted by glowing hydrogen, is determined by the position of the line F in the solar spectrum. If any displacement be observed in the F-line—that is to say, a change in the refrangibility or wave-length of this greenish-blue ray—without *the neighbouring dark lines suffering any displacement at the same time*, it is evident that the cause of this movement cannot be attributed either to the motion of the earth or to that of the sun, but is to be ascribed exclusively to the motion of the luminous hydrogen gas.

If the hydrogen in the sun were rapidly *approaching* us, the number of its ether waves in a second must increase; the length of each wave will become shorter and the light be inclined towards the violet. *The F-line suffers then a displacement from its usual position in the solar spectrum towards the violet end of the spectrum.* If the shortening of the ether waves of this hydrogen line ($H\beta$) be only $\frac{1}{10,000,000}$ of a milli-

metre, the consequent displacement of the F-line can be perceived, and the motion of the hydrogen on the sun be thus demonstrated.

If, on the contrary, this gas be moving in the opposite direction, and be *receding* from us, the number of its ether waves in a second will decrease, the wave-lengths will be augmented, the greenish-blue rays will approach the red, and *a displacement of the F-line will be produced towards the red end of the spectrum.*

FIG. 201.



Direction and Speed of the Gas-streams in the Sun.

With regard to the approach or recession of the hydrogen in reference to an observer on the earth, there are two different circumstances to be taken into account. If the direction of the arrow *a* in Fig. 201 be supposed to denote a luminous stream of gas rising from the sun and *approaching* the earth, that of the arrow *n*, on the contrary, to represent a stream of gas sinking again into the sun and *receding* from the earth, the stream *a* will cause a displacement of the F-line towards the violet, and the stream *n* towards the red, providing the velocity be sufficiently great to alter the wave-length at least $\frac{1}{10,000,000}$ of a millimetre. Tangential or side streams, however, indicated by the arrows *r* and *l*, will have no influence in displacing the F-line; they neither approach nor recede from the eye, their direction being perpendicular to the line of sight L. If, therefore, the telespectroscope be directed to the *centre* of the sun in the direction of the line L,

we shall, in the event of the displacement of the F-line, perceive only the *rising* and *falling* gas-streams a and n, the velocity of which can be measured, but neither of the lateral streams flowing at a tangent to the sun's surface.

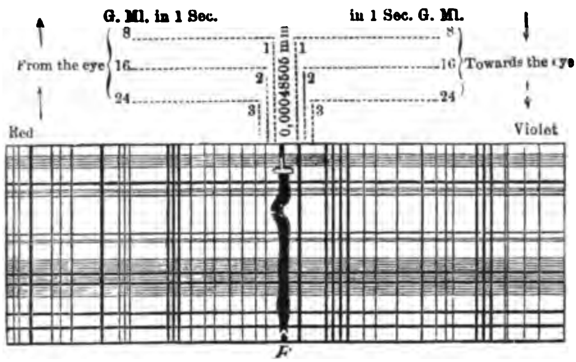
But if the instrument be directed to the sun's limb at R, the case is reversed, and the rising and falling gas-streams a_1 and n_1, inasmuch as they neither approach the eye nor recede from it, and therefore produce by their motion no displacement in the F-line, cannot be perceived. If, on the contrary, the lateral or tangential streams r_1, l_1 be travelling at this spot with sufficient rapidity, the stream r_1 will approach the eye of the observer and cause a displacement of the F-line towards the violet, while the stream l_1, receding from the earth, will produce a displacement of the same line towards the red.

It is evident, therefore, that the rising and falling streams of hydrogen are best observed with the dark F-line in the central part of the sun, while the lateral streams, compared by Lockyer to circular storms, whirlpools, or cyclones, are best observed with the bright Hβ-line on the sun's limb (R or R_1).

If it should happen that the hydrogen lines suffer a simultaneous displacement at both sides, or a uniform increase in width, it is obvious that the inference of motion in the luminous body must be received with caution; the cause of such a widening of either the bright or the dark lines must rather be sought for in an increase of density in the luminous gas. When, however, the expansion of the lines occurs sometimes on one side only, then only on the other, and again unequally on both sides, this cannot, according to the investigations of Lockyer and Frankland, be ascribed to a change in density, since by an increase of pressure the bright line of hydrogen, corresponding with the F-line of the solar spectrum, always expands equally or nearly equally on each side.

Fig. 202, which is from a drawing by Lockyer, shows the remarkable changes that take place in the dark line F when the spectroscope is directed to a solar spot in the middle of the sun. The dark bands passing through the length of the spectrum are occasioned by the general absorption and weakening of the light produced by the substance of the spot. The F-line, which as a rule is sharply defined at the edges, appears in some places not merely as a bright

Fig. 202.



Displacement of the F-line: Velocity of the Gas-streams in the Sun.

line, but as a bright and dark line twisted together, in which parts it suffers the greatest displacement towards the red. When this occurs, there is frequently also a bright line to be seen on the violet side. In small solar spots this line sometimes breaks off suddenly, or spreads out immediately before its termination in a globular form; over the bright faculæ of a spot (the bridges) the line is often altogether absent, or else it is reversed, and appears as a bright line.

The same phenomena are exhibited also by the red C-line ($H\alpha$), though as the greenish-blue F-line ($H\beta$) is by an equal increase of pressure much more sensitive with regard to expansion than the red line is, and exhibits with greater

distinctness the changes that have been already described, it is better adapted to observations of this kind.

All these expansions, twistings, and displacements of the F-line result, as we have already learnt in § 77, from a change in the wave-length of the greenish-blue light emitted by the moving masses of incandescent hydrogen in the sun. The middle of this line, when it is well defined, corresponds to a wave-length of 485 millionth of a millimetre, yet it is possible, by means of Ångström's maps of the solar spectrum (Plates VIII., IX., X., XI.), to measure a displacement of this line when the wave-length has only changed as much as $\frac{1}{10,000,000}$ of a millimetre, and, conversely, it is also possible to read off at once by the measured displacement of the F-line the corresponding amount which the wave-length of the greenish-blue hydrogen light has lengthened or shortened to the ten-millionth of a millimetre. Were the F-line to be displaced from its normal place in the solar spectrum to the spot marked 1 (Fig. 202), the wave-lengths of the greenish-blue hydrogen light would be shortened $\frac{1}{10,000,000}$ of a millimetre; the light would therefore be approaching the eye of the observer, and an eruption of gas be *ascending* at the spot (Fig. 201, *a*) observed in the middle of the sun. It is easy to calculate that such a displacement of the F-line from its normal centre to the spot marked 1 denotes a rate of motion in the glowing gas of thirty-six miles in a second.

If the F-line were to suffer an equal displacement to the left, that is to say towards the red, the wave-length of the greenish-blue hydrogen light would then be lengthened; the gas then would be moving away from the earth at the same rate of thirty-six miles in a second, and the stream of gas be sinking down to the surface of the sun, as indicated by the arrow *n* in Fig. 201.

A displacement of the F-line from its normal centre to the places marked 2 and 3 in Fig. 202, either towards the violet

or the red, would justify the conclusion that the hydrogen was rising from the sun or sinking back to it again at a speed of 72 and 144 miles respectively in a second. From the changes actually observed in the wave-length of the greenish-blue hydrogen light, or from the measured displacements of the F-line, whether bright or dark, it appears that the speed of the gas-streams is usually about 18 miles in a second.

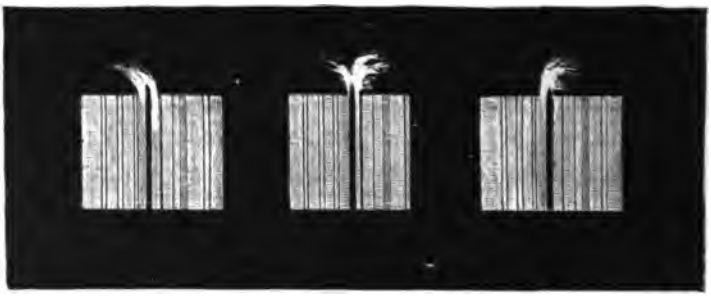
The observation of the *lateral* movements must be made on the bright lines of the chromosphere at the sun's limb either at R or R_1. The speed of the hydrogen is, in this case, much greater, whether it be approaching the earth as at r_1, near R, or at 2 near R_1 (Fig. 201), or whether it be receding from the earth as at n_1 near R, and at 4 near R_1. The changes in the wave-lengths of the hydrogen line occurring at these places are not caused by the rising and falling of the streams of gas a_1, n_1, and 1, 3, but by the lateral motion of the streams r_1, l_1, and 2, 4, and they are evident indications that the glowing hydrogen is in a state of rotatory or cyclonic movement.

It must again be remarked that even with the narrowest setting of the slit, when the opening is not wider than $\frac{1}{500}$ of an inch, a considerable portion of the sun's surface, embracing many hundred miles, is yet visible.

If, therefore, a vortex of glowing hydrogen extending over a space of 900 or 1,000 miles be in rapid revolution in the neighbourhood of the sun's limb, the whole of it may be observed with even the narrowest opening of the slit; in the telespectroscope the ether waves, which are approaching the earth, may be distinguished at once from those which are receding from it, and the motion detected by a corresponding displacement of the F-line. Such a gas-cyclone (Fig. 201, 1, 2, 3, 4) has been observed by Lockyer. When the slit was directed to the middle of the storm, there was an equal

expansion of the F-line both towards the red and the violet, which indicated the velocity of the stream of gas to be rather more than 36 miles in a second. When the slit was moved first to one end of the vortex and then to the other (Fig. 201, 2, 4) it was evident that the ether waves were at one place approaching and at the other receding from the earth, for in each case the displacement of the F-line occurred only on one side. Where the displacement was towards the red, a lengthening of the ether waves had taken place, and consequently the stream of gas (Fig. 201, 4) was receding from the earth; but where the displacement or expansion of the

FIG. 203.



1 2 3

Movement of a Gas Vortex in the Sun.

F-line was towards the violet only, a shortening of the ether waves had occurred, and the stream of gas (2) was approaching the earth.

Fig. 203 shows such a circular storm or cyclone observed by Lockyer on the sun's limb on the 14th of March, 1869. With the first setting of the slit the image of the bright F-line (Hβ) in the chromosphere appeared in the spectroscope, as in No. 1; a slight alteration of the slit gave in succession the pictures 2 and 3. A simultaneous displacement of the bright F-line towards both the red and violet also occurred—a sign that at that place on the sun a portion

of the hydrogen was moving towards the earth, while another portion was going in an opposite direction, and thus the whole action of the gas in motion resembled that of a whirlwind.

In Fig. 204 are given three different pictures of the same hydrogen line of a prominence which Lockyer observed near the middle of the sun on the 12th of May, 1869, together with the dark F-line of the faint solar spectrum. In all these drawings the pointed bright line coinciding in direction with the dark F-line indicates that portion of the prominence or chromosphere which was at rest; these lines

FIG. 204.

32 24 16 8 F 8 16 24 33 24 16 8 F 8 16 24 24 16 8 F 8 16 24

Unequal Displacement of the Greenish-blue Hydrogen Line $H\beta$.

showed unequivocally that the greenish-blue light of the glowing hydrogen had undergone no change in its wave-length, and therefore that the gas was not in motion either towards or away from the earth. The bright lines diverging from these normal lines to the right or towards the violet indicate those portions of the prominences that were in motion towards the earth with very varying velocities. The greenish-blue line of hydrogen, for instance, manifestly underwent a very unequal displacement in the spectroscope; the lower portions, lying close to the dark F-line, showed a smaller displacement and therefore a smaller

change (shortening) of the wave-length than did the upper portions—an indication that the incandescent hydrogen was moving towards the eye of the observer with a velocity greater in the higher and less dense regions of the solar atmosphere than in the lower strata.

Lockyer found that the greatest displacement of the bright F-line corresponded to a velocity in the stream of gas of at least 147 miles a second towards the earth.

These spectroscopic observations receive an additional interest when taken in connection with those made with the telescope. On the 21st of April, 1869, Lockyer observed a spot in the neighbourhood of the sun's limb. At 7 h. 30 m. a prominence showing great activity appeared in the field of view. The lines of hydrogen were remarkably brilliant, and as the spectrum of the spot was visible in the same field, it could be seen that the prominence was advancing towards the spot. The violence of the eruption was so great as to carry up a quantity of metallic vapours out of the photosphere in a manner not previously observed. High up in the flame of hydrogen floated a cloud of magnesium vapour. At 8 h. 30 m. the eruption was over; but an hour later another eruption began, and the new prominence displayed a motion of extreme rapidity. Whilst this was taking place, the hydrogen lines at the side of the spot nearest to the earth were suddenly changed into bright lines, and expanded so remarkably as to give evidence of a cyclonic storm.

The sun was photographed at Kew on the same day at 10 h. 55 m.; the picture showed that great disturbances had taken place in the photosphere in the neighbourhood of the spot observed by Lockyer. In a second photograph, taken at 4 h. 1 m., the sun's limb appeared torn away at the place where the spectroscope had revealed a rotatory storm.

An instance of the remarkable contortions to which the hydrogen line $H\beta$ of a prominence is subject may be quoted

from the observations of Vogel and Lohse, at Bothkamp. On the 5th of March, 1871, a large prominence was observed in which rapid changes were taking place; the bright line was so extremely crooked that it presented the appearance of being twisted round the dark line F of the solar spectrum. The deviations on either side of this line amounted to 0·23 millionths of a millimetre wave-length, which represents a velocity in the gas equal to about twenty miles.

79. The Spectroscope as a Means of proving the Sun's Rotation.

It occurred to both Secchi and Zöllner that from the unequal displacement of the F or the C-line when observed at the two opposite points of the sun's equator, the velocity of solar rotation might be ascertained. As a point on the surface of the sun turned towards the earth moves in the direction from east to west, so a point on the sun's eastern limb must be approaching an observer stationed on the earth, while a point on the western limb must be receding from him. The points upon the sun's equator would have the greatest velocity, amounting to as much as 1·2 miles in a second. If a spectrum line, as, for instance, the C-line, be observed on the eastern limb of the sun which is *approaching* the observer, it will, in comparison with its position when viewed at the pole of the sun's axis, or even in the centre of the sun, appear to be displaced towards the *violet*; while, on the contrary, the same line observed on the western limb of the sun where it is receding from the earth would be seen to suffer a displacement towards the *red*. Secchi has observed similar displacements in the red Hα-line of the chromosphere when compared with the constant dark C-line in the spectrum of the atmosphere visible at the same time. This bright line when viewed on the *advancing* limb in the sun's equator was seen pushed towards the violet, leaving

behind it a narrow strip of the dark C-line visible on the side nearest the red; when examined on the receding limb, the line was pushed towards the red, leaving behind it a narrow strip of the C-line visible on the side nearest the violet.

For these extremely delicate observations Zöllner employed a *reversion-spectroscope* of his own contrivance, the construction of which is as follows:—The line of light formed by a slit or by a cylindrical lens is brought into the focus of a lens which acts as a collimator, rendering all the rays parallel. The rays next pass through the direct-vision Amici system of prisms, so arranged that the refracting edges shall be horizontal and turned in opposite directions. The rays are thus separated into two pencils, and the spectra formed in opposite directions. The object-glass of the telescope, by which the rays are reunited to form one image, is divided in the middle in a direction perpendicular to the refracting edges of the prisms, and each portion mounted micrometrically, so as to move in a direction either parallel or perpendicular to the line of separation. By this means the lines in the one spectrum may be brought into coincidence one by one with those of the other, or the two spectra may be brought into *close contact*, so that one may serve as a vernier to the other, or else one may be made to *overlap* the other. By this arrangement in the case of any displacement in the lines of the spectrum, *this displacement* is *doubled* as the deviation in each spectrum is in an opposite direction.

With this instrument Zöllner was able to measure the distance between the D-lines with a probable error of only $\frac{1}{226}$ of this quantity.

While employing this reversion-spectroscope in June, 1871, Vogel detected upon several occasions an undoubted displacement of the F-line, and of a neighbouring fine line, the cause of which was traceable to the sun's rotation. The fact of rotation was proved by this observation, but measures

of greater delicacy would be necessary to determine the speed of motion.

Langley has devised an apparatus for bringing into comparison the spectra from opposite portions of the solar surface; this he accomplished by a reflecting prism, by which the light from the opposite limbs was brought to meet at the centre of the slit.

In 1876 Young employed a diffraction grating in conjunction with a prism, making use of the latter to separate the overlapping spectra of a higher order. By this means great dispersive power was obtained, and the displacement of the lines was very apparent. The Rutherfurd diffraction grating (p. 125), contained 8640 lines to the inch, and the prism was placed between the grating and the object-glass of the observing telescope. The instrument was attached in the manner of an ordinary spectroscope to a 9½-inch refractor by Clark. The observing telescope and collimator were permanently fixed, and the spectra of the various orders were brought into the field of view by revolving the grating round the plane of dispersion. The lines selected for measurement were the D-lines, a nickel line, and the lines 1463, 1467, and 1474 of Kirchhoff. The slit was first placed in a direction running north and south, so that when placed tangentially to the eastern limb a right ascension motion brought the western limb into the field of view. The observations gave a speed of rotation slightly exceeding that obtained by direct observation. A similar result was obtained by Vogel. Young is of opinion that this is due to a physical cause, and that the solar atmosphere possibly moves forward over the solar surface.* The facts

* [In 1876 Abney was able to show solar rotation, by photographing the spectrum of the H and K-lines with a Rutherfurd grating of 17,200 lines to the inch. The method adopted was to form two images of the sun touching one another, the beam being reflected from a siderostat, and the images thrown on the slit of the colli-

are, however, by no means fully established, and it is, therefore, needless at present to suggest any explanations.

80. The Absorptive Action of the Solar Atmosphere upon Rays of Various Refrangibility.

The existence of a solar atmosphere and its absorptive influence upon the emergent solar rays has long been demonstrated through the labours of various astronomers, among whom Secchi holds a prominent place. As a sequence to these investigations, Professor H. C. Vogel has directed his attention to the effect produced upon the individual rays, for which purpose he has adapted and reconstructed Glan's Spectrum Photometer (see p. 204, etc.). The instrument was attached to the 9-inch refractor of the Berlin Observatory, and so placed that the slit came precisely into the focus of the object-glass. As the telescope was carried forward by clockwork a slight movement in declination would bring any part of the solar image upon the slit. In choosing a standard of comparison, a difficulty presented itself in finding any artificial light that could compare in brilliancy with the intensity of some portions of the solar image.

The idea eventually presented itself to Vogel to employ the sun itself for this purpose. A mirror mounted on a swivel was attached to the instrument by a brass rod about sixteen inches in length, so that the mirror should be out of reach of the shadow of the telescope, and from this mirror the sun's light was directed on to the comparison prism.

With this instrument Vogel has determined the amount of

mator by means of a divided lens. Spectra of great dispersion were thus obtained of opposite limbs of the sun on the same plate and in juxta position one to another. The pictures thus obtained showed a shift of lines in one direction in the morning, none at midday, but a shift in the opposite direction near sunset.]

absorption taking place in the solar light according to its various wave-lengths, as observed along a line from the centre to the edge of the sun. From the individual observations curves were then drawn representing as nearly as possible the results obtained, and in this way a graphic record was made of the diminution of light noticeable from the centre to the edge of the sun. The accuracy of these observations is not so great as if they were made from an artificial source of light, the cause of which is explained by Vogel to lie partly in some amount of disturbance in our atmosphere too slight to be noticed in ordinary observations, but which is very evident in delicate photometric measurements, and partly from unsteadiness in the air, which may seriously affect the accuracy of observations made in the neighbourhood of the sun's limb, where the intensity varies so rapidly.

In the following tables, prepared by Vogel, in which the results are given in hundredths of the sun's radius, it will be readily noticed how greatly the absorption varies in the different parts of the spectrum, and from these observations it is undoubtedly evident that the absorptive action of the solar atmosphere is strongest upon rays of greatest refrangibility or shortest wave-length.

Under the supposition that the diminution of light from the centre to the edge of the sun is caused by an absorbing gaseous atmosphere around the sun, Vogel has further sought to express the observations in a mathematical form. Laplace had already led the way by calculating from Bonguer's observations the amount of absorption exerted by the solar atmosphere, as well as by estimating the brilliancy the sun would have if without an atmosphere.

If it be assumed, which is nearly correct, that the sun without an atmosphere would appear as a disc equally illuminated in every part, the formula given by Laplace takes

a very simple form, and offers a very close agreement with Vogel's observations.

The curve calculated for yellow agrees completely with the curves of observation, but for green, blue, and violet the calculated are more rapid than the observed curves, while

Distance from the Centre of the Sun's Disc.	VIOLET. 412/405 Millionths of a Millimetre.	DARK BLUE. 446/440 Millionths of a Millimetre.	BLUE. 473/467 Millionths of a Millimetre.	GREEN. 515/510 Millionths of a Millimetre.	YELLOW. 585/573 Millionths of a Millimetre.	RED. 658/666 Millionths of a Millimetre.
0	100·0	100·0	100·0	100·0	100·0	100·0
5	99·9	99·9	99·9	99·9	99·9	100·0
10	99·6	99·7	99·7	99·7	99·8	99·9
15	99·2	99·3	99·3	99·3	99·5	99·7
20	98·5	98·7	98·8	98·7	99·2	99·5
25	97·5	97·8	98·1	97·9	98·8	99·3
30	96·3	96·8	97·2	96·9	98·2	98·9
35	95·0	95·6	96·1	95·7	97·5	98·5
40	93·4	94·1	94·7	94·3	96·7	98·0
45	91·2	92·2	93·1	92·6	95·7	97·4
50	88·7	90·2	91·3	90·7	94·5	96·7
55	85·7	87·8	89·3	88·6	92·9	95·9
60	82·4	84·9	87·0	86·2	90·9	94·8
65	78·7	81·7	84·2	83·4	88·0	93·2
70	74·4	77·8	80·8	80·0	84·5	91·0
75	69·4	73·0	76·7	75·9	80·1	88·1
80	63·7	67·0	71·7	70·9	74·6	84·3
85	56·7	59·6	65·5	64·7	67·7	79·0
90	47·7	50·2	57·6	56·6	59·0	71·0
95	34·7	35·0	45·6	44·0	46·0	58·0
100	13·0	14·0	16·0	16·0	25·0	30·0

in the red the calculated is flatter than the observed curve. "I believe," remarks Vogel, "that this discrepancy must not be regarded as a chance, but may be viewed as a reality, the simplest explanation of which would be the hypothesis that the intensity of the light emanating from the sun's surface depends not merely upon the angle of departure, but also upon the wave-length, and that the sun without an

atmosphere, as far as regards the most refrangible rays, would appear as a disc brighter in the centre than at the edges, and with regard to the rays of least refrangibility, would appear somewhat brighter at the edge than at the centre. With this assumption the curves of observation and calculation are brought into closer agreement. Similar observations might possibly be made experimentally upon an incandescent metallic globe if the method of observation could only be sufficiently delicate."

By the use of Laplace's formula the observations obtained by Vogel give the following results for the intensity of the various colours in the centre of the sun's disc :—

Violet.	Dark Blue.	Blue.	Green.	Yellow.	Red.
0·481	0·534	0·577	0·557	0·666	0·794

That is to say, that light emanating from the centre of the disc is reduced by absorption in the solar atmosphere to the above amount. In view of the enormous dimensions of the chromosphere, the absorption is very inconsiderable. A column of air 35 miles in height, at a temperature of zero (C), and under a pressure of 30 inches, reduces the light passing through it by a fourth. The chromosphere assumed to be between 3 to 4 seconds in height, that is to say, from 1,300 to 1,900 miles in depth, reduces the light on an average not more than half.

"It would be interesting," remarks Vogel, "to enter into the question how bright the sun would appear to us without an atmosphere. The result might be obtained from the mathematical data deduced from the observations, but a simpler method is to divide the solar disc into concentric zones, and to multiply the area of the zones by the loss of intensity given by the observations, and to add together the results.

"A calculation of this description, in which the width of

the zones was taken at 0·05—Solar Radius = 1—gives 2·17 for violet, and 2·65 for red. Under the former assumption that the sun without an atmosphere would be equally bright at all points, Vogel finds the intensity of violet 6·45, and of red 3·96. If the sun were without an atmosphere, therefore the violet rays would show an increase of brilliancy of

$$\frac{6{\cdot}54}{2{\cdot}17} = 3{\cdot}01 \text{ times, and the red rays of}$$

$$\frac{3{\cdot}96}{2{\cdot}65} = 1{\cdot}49 \text{ times.''}$$

Professor Vogel also points out the importance of carrying out a series of observations upon the absorptive influence of the sun's atmosphere during the period when the spots are at a minimum, and to repeat the observations when the spots are at a maximum, as it is very probable that the total absorption differs from the results at present obtained, since the temperature of the solar atmosphere must doubtless be sensibly raised by the enormous outburst of incandescent hydrogen gas, and its absorptive energy thereby affected. He further suggests that under especially favourable atmospheric circumstances it would be advantageous to direct extreme attention upon one colour, extending the observations over a greater number of points in the solar radius, in order to discover whether slight differences exist between individual zones in the northern and southern hemispheres, as appears to be suggested by the observations hitherto instituted. It is needless to point out that the spectrum photometer affords an accurate means of determining the various degrees of brightness presented by the spots, the penumbra, and the solar surface.

PART FOURTH.

STELLAR SPECTROSCOPES AND INVESTIGATION OF THE MOON AND PLANETS BY SPECTRUM ANALYSIS.

STELLAR SPECTROSCOPES AND INVESTIGATION OF THE MOON AND PLANETS BY SPECTRUM ANALYSIS.

81. Stellar Spectroscopes.

The investigation of the spectra of the planets and stars commenced by Fraunhofer has since been carried on by Lamont, Donati, Brewster, Stokes, Gladstone, and others; but their labours were restricted to observing the position of the dark lines present in these spectra, as well as their relation to the Fraunhofer lines of the solar spectrum, without discovering their real character or connection with the material constitution of the heavenly bodies. It was not till Kirchhoff's discovery of the theory of the Fraunhofer lines (1859) that the sun, the planets, the stars, the nebulæ, clusters, comets, and even meteors, were subjected to analysis by means of their spectra.

The extreme faintness of the light derived from stars, nebulæ, and comets renders the spectroscopic investigation of these heavenly bodies a task of extreme difficulty, and it is not easy to over-estimate the labours of those observers who have devoted themselves to this branch of science.

It is obvious that the spectroscopes constructed in the manner most suitable for the analysis of terrestrial substances are not adapted for the investigation of stellar light. Whenever the distances of the lines in the stellar spectra have to be measured, or their position compared with the spectrum

lines of any terrestrial substance, the instrument must be attached to an equatorially mounted telescope, turning at the same speed as the earth, but in a contrary direction, so as to keep any star upon which the instrument has once been directed stationary in the centre of the field of view during the whole time of observation. The motion of such an instrument is generally accomplished by clockwork.

The image of a star in a telescope is, as is well known, a point *; now the spectrum of a point is a line without any sensible breadth, and therefore not suitable for observation. In order to obtain a spectrum of sufficient breadth from a luminous point, the point must either first be converted into a short line of light, by the use of a cylindrical lens, and then a spectrum be formed, or a linear spectrum must first be formed, and then a cylindrical lens employed for increasing its breadth.†

It is evident, on account of the faintness of the object, that the dispersive power of the spectroscope must under ordinary circumstances be limited, and the instrument restricted to only a few prisms.

A suitable contrivance in immediate connection with the spectroscope is also advisable, whereby terrestrial substances may be converted into luminous vapour by any of the usual methods, and their light sent into the spectroscope through a comparison prism, covering one-half of the slit, so that the spectra may be compared with the spectrum of a star.

The first stellar spectroscope was made by Fraunhofer in 1823. In order to observe the spectra of the stars, and at the same time to determine the refrangibility of their light, he attached to a telescope of 4½ inches aperture a flint-glass

* [Or rather a disc of very small diameter varying with the aperture of the object-glass used.]

† [The first method is the better.]

prism with a refracting angle of about 37° of the same diameter as the object-glass. The angle formed by the incident with the emergent ray was about 26°. This prism was placed in front of the object-glass of the telescope, so that the latter served as the observing telescope to the spectrum. This plan was abandoned by later observers, who, following the example of Lamont (1838), allowed the light of

FIG. 205.

Merz's Object-glass Spectroscope.

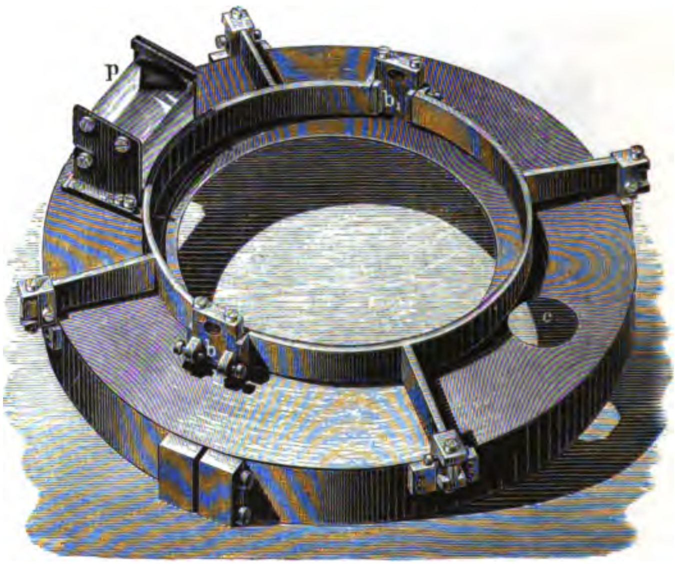
the star to pass unchanged through the object-glass of the telescope, and analysed the image from the eye-piece.

Secchi and Respighi have lately reverted to Fraunhofer's method, and have furnished their large refractors with an *object-glass spectroscope* constructed by the celebrated optician Merz, of Munich.

In Fig. 205 the apparatus is represented ready for attachment to the object-glass of a refractor; Fig. 206 shows the mounting for the prism, and Fig. 207 the prism when

removed from its bed. The prism P is mounted in a ring turning on a horizontal axis, which by means of the lateral pins a, a_1 being inserted between the screws b, b_1, may be fitted into a second ring. This outer ring is made to travel round the case by which the whole apparatus is placed in connection with the mounting of the object-glass, so as to allow the prism being placed in any position or inclined in

FIG. 206.



Merz's Object-glass Spectroscope.

any direction with respect to the object-glass or the axis of the telescope. Since the rays falling on the object-glass are diverted by the prism, the axis of the telescope cannot be pointed direct to the star that is to be observed. In order, therefore, to facilitate the finding of a star, the cell carrying the prism is constructed with an opening at c, through which the star may be viewed direct; on the side of the cell opposite this aperture is attached an achromatic system of

prisms p of equal refracting power with the prism P, by means of which the difficulty of finding a star is much reduced. The prism has a refracting angle of 12°; it is composed of the purest colourless flint glass, so that the loss of light is inappreciable. Its aperture measures six Paris inches; and the mounting is provided, as shown in the drawings, with every necessary contrivance for adjustment.

Although this prism considerably reduces the effective aperture of the refractor, yet the amount of light obtained far exceeds that given by the full aperture of nine inches. When a direct-vision spectroscope is applied to the refractor

FIG. 207.

Merz's Object-glass Prism.

in the place of the eye-piece, the dispersion is, according to Secchi, at least six times as great as the most powerful apparatus applied at the eye-piece tube.*

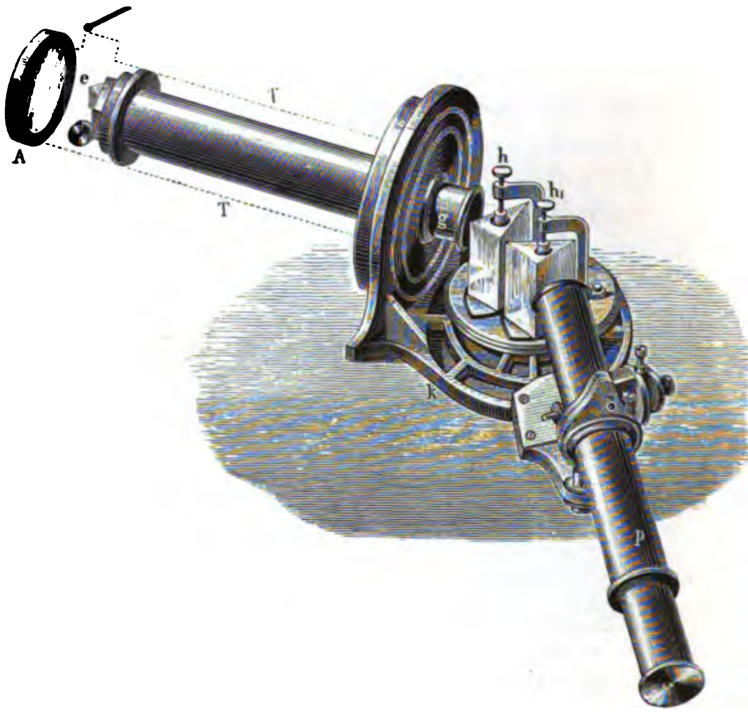
Merz has adapted the object-glass prism for direct-vision observation by constructing it of a combination of crown and flint-glass prisms corrected for refraction. The slight loss of light occasioned by such a combination is unavoidable. In an instrument of this kind made for the observatory of Rüngsdorf, the refracting angle of the crown-

* [This statement needs confirmation. There may have been great loss of light in the direct-vision spectroscopes with which it was compared.]

glass prism is 36°, and that of the flint-glass prism 25°; the mean index of refraction for the crown-glass is 1·5283, for the flint-glass 1·7610.

When an eye-piece spectroscope is employed, either of the methods above described for spreading out the point of

FIG. 208.



Huggins' Stellar Spectroscope (Perspective View).

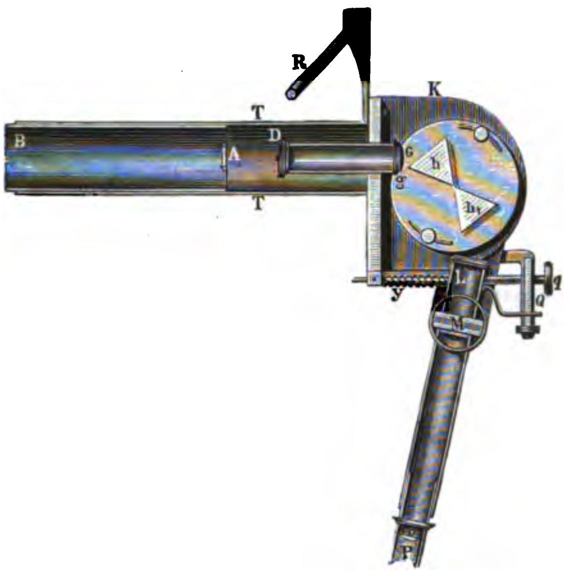
light by the use of a cylindrical lens may be adopted, and it is in most cases a matter of indifference whether this lens be placed in front or behind the slit and prisms.*

The stellar spectroscope with which Huggins made his

* [Dr. Huggins says that this statement is not quite correct. The cylindrical lens should be placed before the slit.]

first observations is represented in Figs. 208, 209, and 210. The outer tube T T of the eye-piece is the only portion of the equatorial telescope given in the drawings; all the other parts are omitted. The spectroscope is attached to the eye-end T T of the telescope, a refractor, the whole being carried forward by clockwork.

FIG. 209.

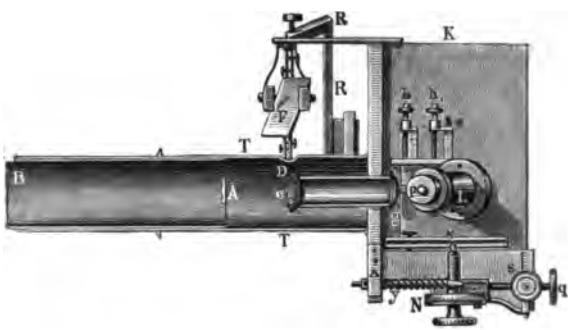


Huggins' Stellar Spectroscope (Horizontal Section).

Within the tube T T of the equatorial there slides a second tube B, which carries a plano-convex cylindrical lens A of 1-inch aperture and 14 inches focal length; this lens is so placed in the path of the converging rays as they emerge from the object-glass that the axis of the cylindrical surface is perpendicular to the slit D of the spectroscope, and by its means a sufficiently broad spectrum of the line of light is formed, the slit D being placed exactly in the focus of the object-glass of the telescope. Behind the slit is the collimating

lens *g*, by which the rays are rendered parallel before entering the prism; the lens is achromatic, and has a focus of 4·7 inches, and an aperture of half-an-inch. By this arrangement the lens *g* receives all the light which diverges from the linear image of the star when this has been brought precisely between the two edges of the slit. The parallel rays emerging from the lens *g* pass through two dense flint-glass prisms *h*, h_1, with a refracting angle of 60°, by which a spectrum is formed, examined by means of the small achromatic telescope *p*. In order to measure the distances

FIG. 210.



Huggins' Stellar Spectroscope (Partial Vertical Section).

between the lines of the spectrum, the telescope can be turned upon a pivot by means of a fine micrometer screw *q y*.

The object-glass of this observing telescope has an aperture of 0·8 inch, and a focal length of 6·75 inches; the eye-piece usually employed has a magnifying power of 5·7 times; the micrometer screw is so contrived that it is possible to measure with accuracy an interval of $\frac{1}{1800}$ of the distance between the lines A and H of the solar spectrum.

The light of the terrestrial elements, the spectra of which are required for comparison with the spectrum of a star, is brought into the spectroscope in the following manner.

One half of the slit D is covered with a small prism *e*,

opposite to which is a mirror F (Fig. 210), so fastened to the spectroscope by the arm R as to be easily adjusted. The substance to be converted into luminous vapour by the induction spark is held in the right position by metal forceps fixed into ebonite. The light emitted is received by the mirror F, whence it is reflected through a side opening in the tube T T into the telescope, and on to the little prism *e*. While the light of the star passes through one half of the slit, the light from the glowing terrestrial substance passes through the other half, and in this way there are formed in the telescope *p* two spectra in juxtaposition, so that the coincidence or non-coincidence of the dark lines of the star with the bright lines of the terrestrial substance may be observed with accuracy.

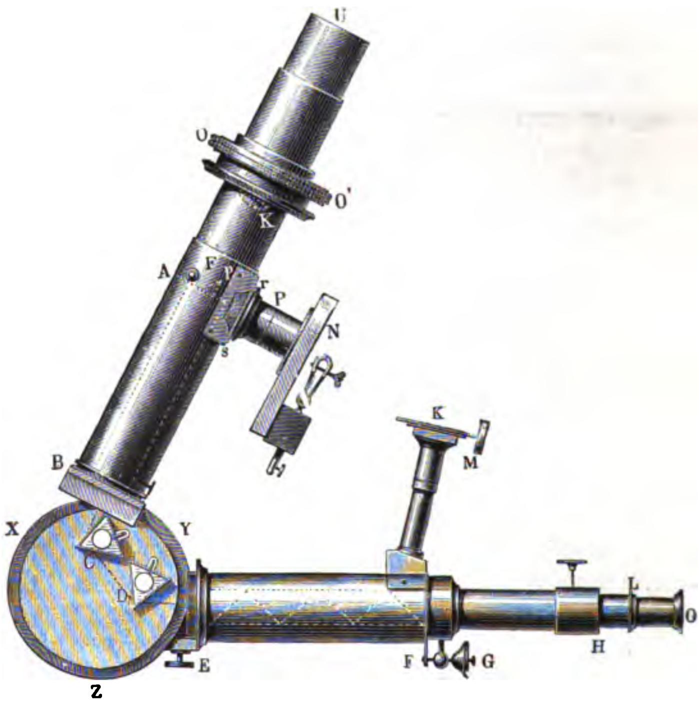
In his researches on stellar spectra, Secchi employed by preference a simple direct-vision spectroscope, as a more complicated apparatus when attached to an equatorial is liable to destroy the equilibrium of the instrument, and interfere with the regularity of the clock motion.

In order to see the finer dark lines of the spectra, and to compare them with the lines of terrestrial substances, instruments composed of single and compound prisms have been constructed both by Huggins and Secchi, suitable for application to powerful telescopes which admit of a great dispersion of the light.

A sketch of Secchi's compound spectroscope without the equatorial is given in Fig. 211. By means of the screw O O^1 the instrument is attached to the eye-piece tube of the refractor; at K is a cylindrical lens by which the image of a star appearing as a point is extended into a fine line of light, and brought precisely within the opening of the slit. F is the slit, half of which is covered with the comparison prism *p*, B the collimating lens for bringing the rays on to the first prism C in a parallel direction. Both prisms C and D are of

dense flint glass, with a refracting angle of 60°, and are fastened on to the plate X Y Z. They throw the spectrum of the star into the axis of the direct-vision spectroscope E F H O, which contains the compound prism E F, con-

FIG. 211.



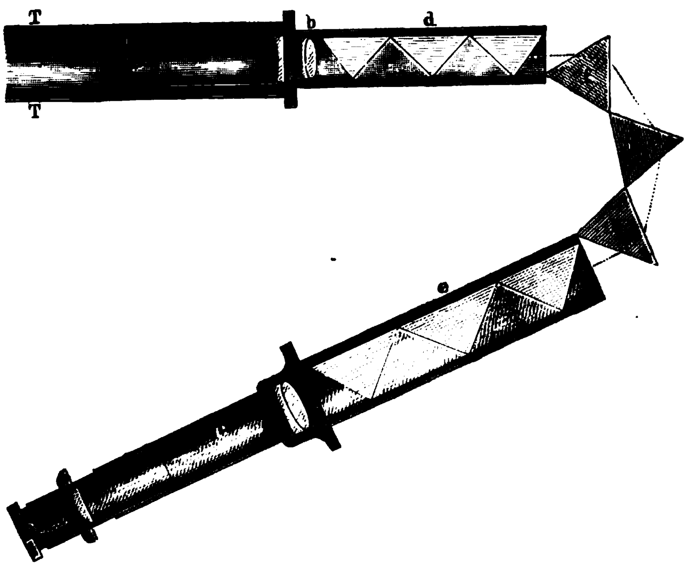
Secchi's Large Telespectroscope.

sisting of five prisms, the observing telescope H O, and the lateral tube K with a graduated scale. This scale is moved by the micrometer screw M, and when the instrument is in use is illuminated in the usual manner by a lamp flame; the image of the scale is reflected by the last prism into the telescope O, and appears in the same field of view with the

spectrum of the star. N is a holder for receiving a Geissler tube.

Huggins' large compound telespectroscope is shown in Fig. 212; it consists of *two* direct-vision systems of prisms, each system composed of five prisms, with a train of three excellent single prisms, two of which, *f* and *g*, possess a refracting angle of 60°, and one, *h*, of 45°, making thirteen

FIG. 212.



Huggins' Large Telespectroscope.

prisms in all. The spectroscope is screwed into the eye-tube T T of an equatorial, driven by clockwork: *a* is the slit provided with a comparison prism, and an arrangement for obtaining the spectrum of a terrestrial substance; *b* is the achromatic collimating lens of 4·5 inches focus for rendering parallel the rays entering the slit. The light is first decomposed by the set of prisms *d*, then further dispersed by the train of prisms *f*, *g*, and *h*, after which it again passes through

a second direct-vision system of prisms *e*, to reach the object-glass of the observing telescope *c*. The last set of prisms *e* is placed in a tube attached to the telescope *c*, which by a micrometer screw can be directed to any part of the spectrum.

The compound prism *e* can be employed or dispensed with at pleasure, so that the dispersive power of the instrument may be made to vary within the limits of from $4\frac{1}{2}$ to $6\frac{1}{2}$ prisms of 60°. The advantage of being thus able to reduce the dispersive power of the instrument is very great

FIG. 213.

Schröder's Spectrum Apparatus attached to the Bothcamp Refractor.

when observing faint objects, or when the atmospheric conditions are unfavourable.

The excellence of the instrument is shown by the purity and definition of the spectrum, even with high powers, when metals are volatilized in the electric spark.

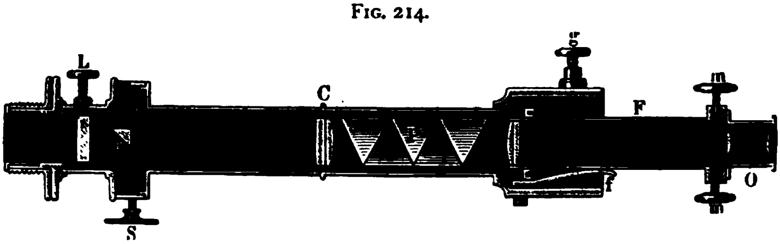
The stellar spectroscope constructed by Schröder for the Bothcamp Observatory, and employed by Vogel and Lohse in their valuable series of observations, is represented in Fig. 213. The lower end of the telescope A is closed by the iron plate B, in which is a circular opening about 3 inches in diameter. Upon this plate the spectrum apparatus is attached by the four screws 1, 2, 3, 4. The four supports *a* are

secured not only to the cylindrical cap *b*, but also to the disc *c*, by which arrangement great stability is insured to the apparatus. The tube *d* is introduced through the disc *c* into the cylinder *b*, and carries an index *e*, travelling upon the divided circle *c*. The revolution of the tube *d* can be accurately read to within $\frac{1}{4}$ of a degree upon the divided circle, the diameter of which is about $5\frac{1}{2}$ inches. At one end of the tube *d* is the slit *f*, the steel plates of which are adjusted by a micrometer screw. The tube *g* is for the reception of the cylindrical lens. At the other end of the tube *d* is screwed the plate *h*, carrying two metal cubes (only one of them is shown in the figure), in which is fixed the axis of the plate *l*, and the telescope *m*. Into one end of the plate *l* the micrometer screw *k* works, by which the plate *l* can be moved to or from the plate *h*. To obtain this motion the rounded end of the micrometer screw is firmly pressed against a piece of polished steel in the plate *h* by a strong spiral spring coiled round the pin *i*. The complete revolutions of the screw are registered on the divided arc *n*, while parts of a revolution are registered on the screw head by the index *o*. The tube *d* contains the collimator lens of $\frac{9}{10}$ of an inch aperture, and $9\frac{1}{4}$ inches focal length, as well as five direct-vision prisms $\frac{4}{8}$ of an inch high, with a refracting angle of 90°. The object-glass of the telescope is of the same aperture and focal length as the collimator lens. The eye-pieces of the telescope have a magnifying power of four and five times respectively, and together magnify nine times. In the tube *g* there are two other cylindrical lenses, one convex and the other concave, which can be brought in front of the slit. The performance of the instrument, as Professor Vogel has expressed himself, leaves nothing to be desired. The lines are exquisitely sharp, and with the highest power the faintest lines in Ångström's map of the solar spectrum are visible.

In constructing the instrument Schröder has taken special care to make use of all the rays coming from the object-glass of the large telescope, and has adapted the size of the collimating lens of the spectroscope to the size of the cone of light issuing from the object-glass, a point often neglected in adapting the spectroscope to large instruments.

For most purposes, however, especially when applied to small refractors, an instrument of simpler construction is preferable, such as the direct-vision spectroscope furnished by Merz of Munich for the observation of the solar prominences. When attached to the telescope it takes the place of the eye-piece, and when used for stellar work the cylindrical

FIG. 214.



Merz's Simple and Compound Spectroscope.

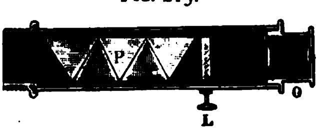
lens L (Fig. 214) is inserted so as to project the linear image of the star into the slit *s s*. As there is no means of altering the distance between L and *s*, the exact adjustment of the line of light on to the slit is accomplished by screwing the whole instrument in or out. In observing star spectra, when the light is sufficient to allow it, the dispersive power may be doubled by the introduction of a second system of prisms, without losing the advantage of a direct-vision spectroscope.

A simple stellar spectroscope is also constructed by Merz adapted specially to telescopes of small power. A drawing of this instrument is given in Fig. 215; it consists of a positive eye-piece O, an adjustable cylindrical lens L, and

a direct-vision system of five prisms, the dispersive power of which amounts to 8° from D to H. It is so contrived that the prisms, when separated from the lens L and the eye-piece O, may be easily introduced between the collimator C and the system of prisms of the larger spectroscope (Fig. 214). The two instruments (Figs. 214 and 215) thus form a *universal eye-piece spectroscope* admirably adapted to astronomical work.

Even Browning's miniature spectroscope (Fig. 216), measuring only 3½ inches, shows a fine spectrum if directed on to a bright star, in which the prominent dark lines are distinctly visible. For stellar observations, the tube containing the slit is removed, and the collimator tube O screwed into the place of the eye-piece of the telescope. The spectroscope is easily so adjusted that the image of the star is brought into the focus of the lens C, whence the rays are thrown in a parallel direction on to the system of prisms P, and form at O a sharply defined linear spectrum of the star. To give this spectrum a sufficient breadth to allow the dark lines to be visible, it must be viewed through a cylindrical lens, whose axis shall be perpendicular to the refracting angle of the prisms.

FIG. 215.



Merz's Simple Spectroscope.

For faint stars L. Camphausen has advantageously employed a stellar spectroscope, consisting of a spherical lens of short focus, a direct-vision system of small prisms, and a cylindrical lens which could be introduced or withdrawn at pleasure. From the telescopic image an image of a star is formed by the condensing lens in front of the prisms by their action, and is converted into a linear spectrum, which may be sufficiently widened by the use of a cylindrical lens as to be observed without the aid of an eye-piece. Vogel

was so surprised and delighted with the efficiency of this instrument that he gave it a new form in which it might be used even for micrometric purposes. The prisms P (Fig. 217) are inserted in the tube B, at the lower end of which is the spherical lens *b*, while at the upper end is the cylindrical lens *a*. At the upper part of the tube B, opposite the terminal surface of the prisms, is inserted the tube C, at the further end of which is the spherical lens *e* of low power. Over C slides the tube D, which carries at S either a slit or a scale photographed on glass. A is an outward tube, furnished with springs, within which B is made to slide. By the screw *w* it can be attached to the telescope in place of the eye-piece.

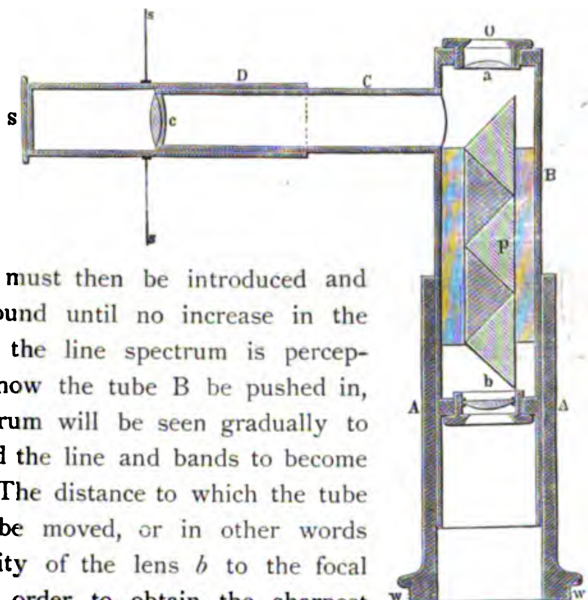
Fig. 216.

Browning's Miniature Spectroscope.

If the cylindrical lens *a* be removed and the eye placed at O, a spectrum of the image in the focus of the telescope may be obtained by adjustment of the tube B. If the object be a star, the spectrum will be very minute. By use of the cylindrical lens *a* a sufficient width of spectrum may be obtained either by placing the axis of the lens—the cylindrical, not the optical axis—perpendicular or parallel to the refracting edge of the prisms. If perpendicular, the outer tube B—starting from the position where the cylindrical lens was removed—must be withdrawn a little; if parallel, somewhat pushed in. The lines of the spectrum will then be distinctly visible. Experience shows that the best image is obtained when the cylindrical axis of the lens is placed parallel to the refracting edge of the prisms. For purely spectroscopic

purposes the position of the cylindrical lens is a matter of indifference, but if measures are to be taken, the parallel position is the only trustworthy one. Professor Vogel gives a rule to facilitate the correct placing of the cylindrical lens. Before the lens is applied the tube B must be pushed in until the spectrum is as concentrated and sharp as possible;

FIG. 217.



Section of Vogel's Stellar Spectroscope.

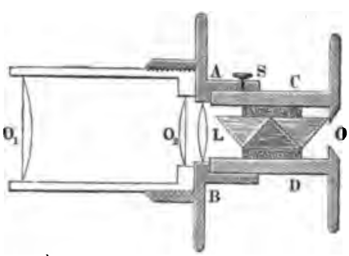
the lens must then be introduced and turned round until no increase in the width of the line spectrum is perceptible; if now the tube B be pushed in, the spectrum will be seen gradually to widen and the line and bands to become visible. The distance to which the tube B must be moved, or in other words the vicinity of the lens *b* to the focal point, in order to obtain the sharpest possible spectrum lines, depends naturally upon the focal length of the lenses *b* and *o*, and also to some extent upon the eye of the observer.

Without moving the telescope it is possible to estimate the distance between the individual bands by their difference in right ascension. The slit S, illuminated by a lamp placed in front of it, serves as a starting-point. In order to shade the eye from the light of this lamp a screen *s s* is attached to the tube D. The lens *c* is to contract the field of view so

as to secure definition and avoid extreme length in the lateral tube. When employed with instruments having clock motion, the slit is replaced by a transparent scale which, when illuminated, is visible in the same field of view with the stellar spectrum.

A very efficient and convenient instrument is Zöllner's eye-piece stellar spectroscope. Fig. 218 gives a sectional view of it. It consists of a small direct-vision system of prisms mounted in a tube C D, which slides in an outer tube A B, by which it can be attached to the eye-piece, and in which is a cylindrical lens of about 4 inches focal length. The lenses O_1 and O_2 are the two lenses of the eye-piece, and, therefore, do not belong strictly to the spectroscope. When the spectrum of a star is to be observed, the tube C D inclosing the prisms is removed, and the eye-piece so adjusted that a sharp line of light is visible from O.

FIG. 218.

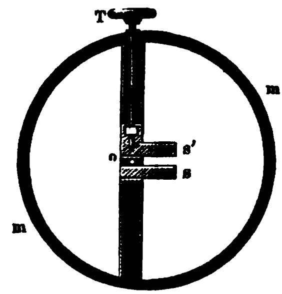


Zöllner's Spectroscope in Eye-piece Tube.

It is important that the eye preserves the same distance from the lens L as when the prisms are in use. The tube C D is then adjusted so that the refracting edge of the prisms is parallel to the line of light, and the greatest width thus given to the spectrum. The luminous power of this spectroscope is considerable, and, in conjunction with its compactness, renders it available for many purposes, but it is unsuitable for objects of large size or for micrometric observations. These inconveniences have been remedied by Vogel by a very simple contrivance. In the tube of an eye-piece of low power (Figs. 219 and 220) a ring *m* is introduced carrying a small bar, upon which rests the slit *s* and s^1, the width

of which is regulated by the screw T. The position of the eye-piece in the outer tube can be so adjusted that the slit can be brought instantly into view. As it occupies but a small part of the field of view, it does not lessen the facility of finding the object, which may be then readily placed within the slit. In objects of great extent, such as a comet or nebula, only a small portion is admitted, the shape of the slit, which may be analysed by the eye-piece spectroscope, from which the cylindrical lens has been removed.

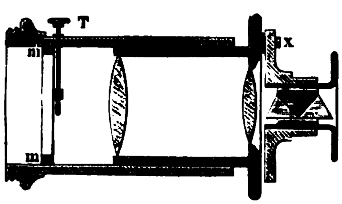
FIG. 219.



Eye-tube Spectroscope with Contrivance for Measuring.

As it is important that the refracting edge of the prisms be kept parallel to the slit, it is convenient to be able to turn the spectroscope upon a lateral axis *x* when in searching for an object the slit has to be removed from the eye-piece. The correct position in front of the eye-piece is indicated by a projecting pin.

FIG. 220.

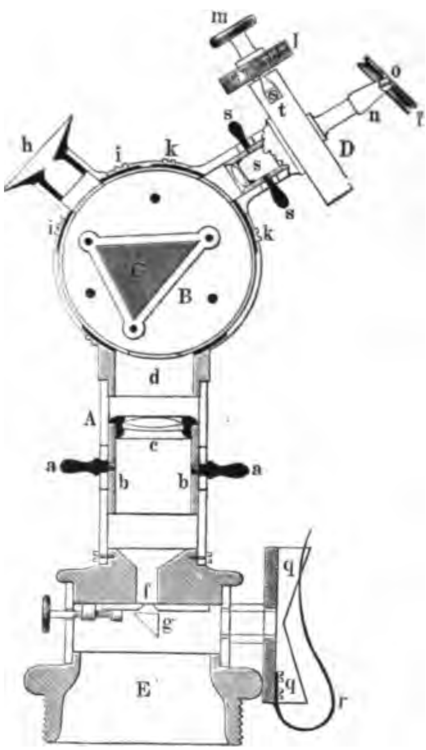


Section of Eye-tube Spectroscope.

When a second spectrum is needed the comparison prism is placed behind the aperture in the bar at *o*, and illuminated from a Geissler tube, attached to the outside of the instrument. The aperture *o* becomes the source of light, and forms a spectrum in juxtaposition to the spectrum of the object to be observed. This instrument when applied to a 6-inch refractor yields spectra of remarkable brilliancy and admirable definition.

A small universal spectroscope, well adapted for the observation of fixed stars or comets, is shown in Fig. 221. E is a metal ring which screws into the eye-piece tube of a telescope. In connection with this ring is a second ring, carrying the slit which is adjustable by a screw. The comparison prism is at *g*, in front of which a Geissler's tube *q q* can be held against the plate by the spring *r*. Into the ring holding the slit is screwed the collimator tube A, into the other end of which the brass supports *d* are fastened. Within the collimator tube slides a second tube *b b*, containing the achromatic collimator lens. By the handles *a a*, the tube can be adjusted so as to bring the slit into the focal point. Upon the supports *d* is screwed the brass plate B carrying the prism C. To this plate is attached by the four screws *i i*—of which two only are visible—the eye-piece diaphragm *h*, and by the screws *k k* the micrometer screw D.

FIG. 221.



Section of Von Konkoly's Universal Spectroscope.

The prism rests upon a small table, the support of which

passes through the brass plate, and is held on the other side by a clamp fixing it in any position. On either side the clamp are two side screws, for obtaining the delicate motion requisite for placing the prism in the attitude of minimum deviation. Automatic motion is unnecessary, the dispersion being so small that the whole spectrum may be viewed at once. The instrument is without a telescope; and in observing the fixed stars a cylindrical lens is introduced in the aperture of the diaphragm at *h*.

The independent adjustment of the different parts of the instrument is secured in the following manner. Around the walls of the central case B, which is soldered to the body of the plate and attached to the cover by three projecting screws, revolves a tight-fitting tube working in a groove both in the plate and cover. From this tube at three different places three broad stripes are cut away, so as to leave only three entirely independent segments remaining. Upon these are respectively fastened the collimator tube A by its supports *d*, the small collimator tube with the micrometer D, and the eye-piece diaphragm *h*. Each is attached to the cylinder B by four screws, but the screws *i i* and *k k* are placed in elongated apertures so as to allow of a certain amount of motion.

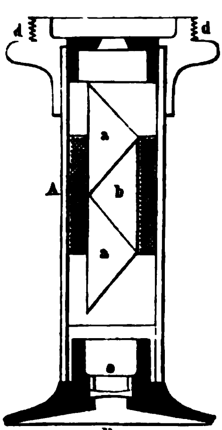
The position of the lines, as they become visible in the eye-piece *h*, can be read off on the divided circle *l*. The turning of this screw, effected by the knob *m*, gives motion to a line of light inserted in a plate travelling in the hollow slide D. The line receives illumination from the mirror P, resting on the support *n*, and its image is formed on the surface of the prism opposite the eye-piece *h*, by the biconvex lens *s* (see p. 81, Fig. 45 *b*). A reflection from this image enters the eye of the observer at the same time as the spectrum viewed direct.

The apparatus is also furnished with a second flint-glass

prism with a refracting angle of 69° when a higher power is needed.

The efficiency of this instrument is further increased by the addition of a small Zöllner eye-piece spectroscope (Fig. 222), which can be screwed on to the instrument in place of the eye-piece. The ring *d* can be unscrewed from A (Fig. 221) and substituted for the eye-piece, in which case a cylindrical lens is introduced at *h* in order to give additional breadth to a stellar spectrum. The line of light of the micrometer is in no way distorted by the cylindrical lens; the two ends are merely drawn to a point by which the definition is rather increased.

FIG. 222.



Eye-tube Spectroscope.

We must not omit all mention of the simple spectroscopes which are of wide adaptation. Huggins has long made use of a hand spectroscope for observing the spectra of meteors and other phenomena in rapid motion.

These instruments consist principally, as shown in Fig. 223, of a direct-vision system of prisms *c*, composed of one of dense flint glass and two of crown glass, and an observing telescope *a b*. The achromatic object-glass *a* has an aperture of 1·2 inch, and a focus of about 10 inches. The eye-piece *b* consists of two plano-convex lenses. As a large field of view is very important, especially when the instrument is employed as a meteor-spectroscope, the lens turned towards the object-glass *a* equals it in diameter, and is fixed in a movable tube, so that the distance between the two lenses of the eye-piece may be controlled, and the power of the instrument thus increased or diminished. The field of view embraces a space in the heavens of about 7° in dia-

meter; the spectrum of a bright star has an apparent length of 3°, and that of the great nebula of Orion appears as two bright lines with a faint continuous spectrum.

For the purpose of testing the instrument as a meteor-spectroscope, Huggins observed the spectra of some fireworks at a distance of about three miles. The bright lines of the incandescent metals were distinctly seen, and revealed the presence of sodium, magnesium, strontium, copper, and some other metals. This instrument is able to show some of the Fraunhofer lines in the spectrum of the extreme points of the moon's cusps, as also the dark lines in the stellar spectra. In order to give breadth to the linear spectrum of a star, a cylindrical lens is placed over the

FIG. 223.

Browning's Hand-spectroscope.

eye-piece. As the instrument is without a slit, it can only be used on bright objects of small magnitude, or on objects at such a distance that they have only a small apparent size.

82. SPECTRA OF THE MOON AND PLANETS.

Since the planets and their satellites do not emit any light of their own, but shine by the reflected light of the sun, their spectra are the same as the solar spectrum, and any differences that may be perceived can arise only from the changes the sunlight may undergo by reflection from the surfaces of these bodies, or by its passage through their atmospheres.

The observations of Fraunhofer (1823), Brewster and Gladstone (1860), Huggins and Miller, as well as Janssen,

agree in establishing the complete accordance of the lunar spectrum with that of the sun. In all the various portions of the moon's disc brought under observation, no difference could be perceived in the dark lines of the spectrum either in respect of their number or relative intensity. From the absence of any special absorption lines, it would seem that there is little or no atmosphere in the moon.

The spectrum of the moon during a total eclipse was observed at Greenwich on the 23rd of August, 1877. During totality, as the moon appeared of the usual deep copper colour, a strong absorption band was seen in the yellow, and both the red and the blue end of the spectrum were suddenly broken off, while the orange portion seemed faint. At first it appeared as if yellow and green made up the whole visible spectrum. The wave-length of the most refrangible end of the strong absorption band was, from the mean of nine measures, 5624 millionths of a millimetre. As totality drew to a close, the band became narrower, and as the light increased, it was reduced to a line. The band corresponds with the atmospheric band δ, observed by Brewster, and is doubtless due to dense strata of vapour in our atmosphere. The light by which an eclipsed moon is visible passes through a thick stratum of our atmosphere, and hence arises the deep copper colour.

In the spectrum of the planets Mercury, Venus, Mars, Jupiter, etc., the Fraunhofer lines characteristic of sunlight are apparent; while in the spectra of some there are in addition absorption lines indicating a vaporous atmosphere. By the process which he employed in his investigations on the stars, described later on, Huggins succeeded in photographing the spectra of Venus, Mars, and Jupiter. In the best of these photographs the Fraunhofer lines can be distinctly seen from *b* to S in the ultra-violet, and the smallest deviation from the lines of the solar spectrum

would be immediately detected. Huggins, however, was unable to discover either any modification in the solar light or any additional absorption lines.

Between the years 1871 and 1873, the spectrum of Mercury was repeatedly observed by Vogel and Lohse at the Bothcamp observatory. It was found always in perfect agreement with the solar spectrum with the exception of two bands, "which possibly were not entirely due to the absorption in our atmosphere, but might in part be caused by absorption of the solar rays in the gaseous envelope with which Mercury is surrounded." Vogel himself remarks, however, that this question must remain undecided as long as the observations are of necessity made after the sun is set, and consequently when the planet is near the horizon.

The spectrum of Venus has been examined by Secchi, Huggins, and Vogel. It does not differ essentially from the solar spectrum, yet, according to Vogel, some fine bands are present which correspond with the lines of our atmosphere, and may, therefore, be due to vapour.

The spectrum of Mars has been studied by Secchi, Huggins, Rutherfurd, and Vogel, the observations of the latter being the most complete. In this spectrum also numerous lines of the solar spectrum are to be recognized. In the least refrangible parts some bands are present which do not belong to the solar spectrum, but which coincide with the absorption spectrum of our atmosphere. They are as follows:—

Wave-lengths millionths of a millimetre.	
687·7	Middle of a broad dark band, sharply defined towards the violet (Telluric lines in the neighbourhood of B).
655·5	Middle of a dark band (Telluric lines in the neighbourhood of C).
648·7	Middle of a tolerably dark band (Telluric lines).
627·9	Middle of a band (Telluric group of lines, *a* Ångström, C^{s} Brewster).

Wave-lengths millionths of a millimetre.

594·8 Faint bands } Telluric system of
592·0 Faint bands } lines near D.
580·0 } Faint bands (Brewster's Telluric
570·0 } group of lines δ).

FIG. 224.—Spectrum of Jupiter.

From this Vogel makes the confident deduction that Mars possesses an atmosphere in constitution differing little from our own, but characterized by great moisture. The red colour noticeable in Mars seems to be due to a general absorption of the blue and violet rays in its atmosphere, since no distinct absorption bands are to be observed in this portion of the spectrum. In the red portion between C and B some bands are suspected—for instance, a band at 661 millionths of a millimetre of wave-length—which must belong to the absorption spectrum of the atmosphere of Mars, but for want of light the positions could not be determined.

Of the asteroids Vogel has yet observed but Vesta and Flora. Vesta shows but two bands, one of which seems to coincide with the atmospheric band δ. In the spectrum of Flora no lines are visible.

The spectrum of Jupiter was first examined by Rutherfurd, and afterwards by Secchi, Huggins, and Le Sueur, but in this case also Vogel's measures are the most complete. This spectrum (Fig. 224) differs from the solar spectrum through the presence of some bands

which occur chiefly in the least refrangible portion of the spectrum, among which the most striking is a dark band in the red, 617·85 millionths of a millimetre wave-length.

The remaining bands not present in the solar spectrum are as follows :—

Wave-lengths millionths of a millimetre.	
656	Middle of a broad dark band (Telluric lines near C[a]).
649·5	Middle of a broad dark band (Telluric lines).
628	Faint band (Telluric group of lines C[a] Brewster, *a* Ångström).
594·5 / 592·0	Faint band (Telluric group of lines in the neighbourhood of D).
580 / 570	Pale band washed out towards the violet (Telluric band δ, Brewster).
524·8	Faint band (presence suspected in the absorption spectrum of our atmosphere).
507 / 500	Pale band (Telluric lines).

While in the less refrangible portion of the spectra of the planets individual bands appear, there takes place a more uniform absorption, according to Vogel, in the blue and violet portions. "From this it appears that the gaseous envelope with which Jupiter is surrounded exerts upon the solar rays which penetrate it a similar influence to that exerted by our atmosphere, whence we are justified in deducing the presence of vapour in the atmosphere of Jupiter. The excessively dark band in the red mentioned above is peculiar to the spectrum of this planet. The question must for the present remain undecided whether it is due to the existence of some substance absent in the constitution of our atmosphere, or whether it is due merely to a difference in the proportions of the component gases. It is even possible that such a change in the absorption spectrum might take place without any alteration in the proportions of the component gases, but merely from such change in temperature and pressure as Jupiter's condition must necessitate.

"From observations hitherto made the spectra of the dark belts that traverse Jupiter seem chiefly characterized by the strong general absorption to be noticed in the blue and violet. No new absorption bands are visible, but an increase in breadth and strength is noticeable, which seems to show that the dark portions form the deepest strata. The solar light must have passed through a greater depth of atmosphere, and have been in consequence more seriously affected.

"The red colour of the planets, and especially the red colour of the darkest parts of Jupiter, is to be explained by the general absorption exerted by their atmosphere upon the most refrangible rays."

Vogel has also examined the spectrum of the fourth satellite of Jupiter. It was very faint, and the red was entirely wanting, as it reached only from D to half-way between F and G. Besides a dark band corresponding with F, there were two other dark portions to be noticed at wave-length 567 and 527 millionths of a millimetre. The latter band coincided with E.

The results of the examination of Saturn's spectrum have been reviewed by Vogel, and he has shown that the most prominent of the lines in the solar spectrum are to be recognized. "There are some bands not in coincidence with the solar spectrum, especially in the red and in the orange. These coincide with groups of lines in the absorption spectrum of our atmosphere, with the exception of a very intense band, the wave-length of which, taken from the mean of several observations during various evenings, is 618·2 millionths of a millimetre. The blue and violet rays in passing through the atmosphere of Saturn suffer a general absorption, which is especially manifest in the spectrum of the dark equatorial belt. The spectrum of Saturn, therefore, is entirely uniform with that of Jupiter."

It is otherwise with the spectrum of Saturn's rings, in

which the characteristic band in the red is absent, or at least very faintly indicated, whence it may be concluded that if there is any gaseous envelope, it must be one of great rarity or little depth.

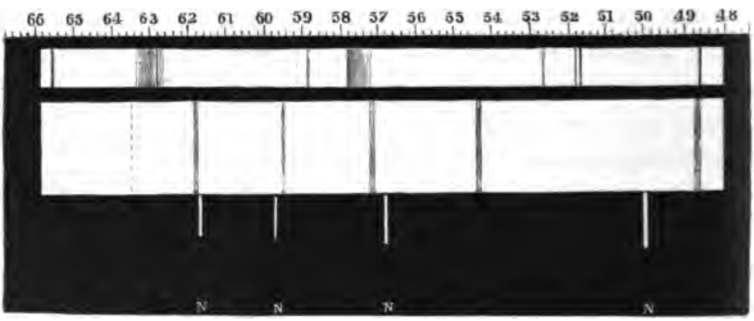
The spectrum of Uranus, first investigated by Secchi, appears to be of a very remarkable character. It consists mainly of two broad black bands, one *m* (Fig. 225) in the greenish-blue, but not coincident with the F-line, and the other *n* in the green near the line E. A little beyond the band *n* the spectrum disappears, and shows a blank space *q p*, extending entirely over the yellow to the red, where there is again a faint reappearance of light.

It is very remarkable that the spectrum of Uranus as observed by Huggins and Vogel is quite different from that observed by Secchi. Huggins' drawing of the spectrum of Uranus is given in Fig. 226. The lower narrow spectrum is that of the sun, the upper spectrum that of Uranus. For the sake of comparison, the strongest absorption bands of the earth's atmosphere are introduced into the solar spectrum —namely the band near D (more refrangible than D) and the group of lines occurring about the middle between C and D. The scale beneath the solar spectrum gives the wave-lengths in millionths of a millimetre.

Fig. 225. Spectrum of Uranus as observed by Secchi.

In the spectrum of Uranus no gap occurs from near C in the red to G in the blue, but it is difficult in so faint a spectrum to distinguish the individual colours. Owing to the deficiency of light, the slit had to be too widely set for the recognition of the Fraunhofer lines, but the absorption bands due to the planet's atmosphere were so marked that their position could be determined with tolerable facility, either by the micrometer or by comparison with a terrestrial substance —nitrogen (N), for instance. These consist principally of six broad bands, of which the least refrangible occurs in so

FIG. 226.



Spectrum of Uranus as observed by Huggins.

faint a portion of the spectrum that its position—indicated in the figure by a dotted line—can only be approximately estimated. The positions of the five other bands were measured micrometrically during several successive nights. The strongest line corresponds with a wave-length of about 544 millionths of a millimetre, while the band at 572 of the scale is quite as broad, though not quite so dark. The band nearest the refrangible end of the spectrum occurred at F, or exceedingly near to F. A comparison with hydrogen by means of a Geissler tube showed its coincidence with the line $H\beta$.

The positions given by the micrometer for three bands made it probable that they were identical with some bright lines in the air spectrum, but a comparison with the spectrum of nitrogen showed that the absorption band, answering to a wave-length of 572 millionths of a millimetre, is less refrangible than the contiguous double line of nitrogen. The bands situated at 595 and 618 of the scale were very nearly coincident with bright lines in the spectrum of air.

The faintness of the spectrum of Uranus precludes great accuracy, but it appears as if the planetary bands were only slightly less refrangible than the air lines.

A comparison between the spectrum of Uranus and that of carbonic acid gas shows that the absorption bands are not due to this gas, nor are they coincident with the D-line, nor with any of the principal lines in the air spectrum.

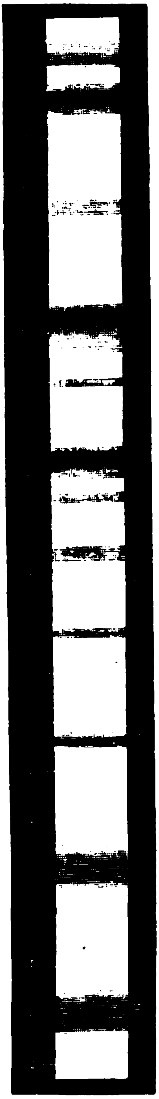


FIG. 227.—Spectrum of Uranus as observed by Vogel.

Vogel thus condenses his results: "The spectrum of Uranus (Fig. 227) is too faint to permit of any Fraunhofer lines being perceived, yet the middle of one of the absorption bands (δ) agrees, within the limits of error of measurement, with the line F. In the spectrum of Uranus there are five bands, the wave-lengths of which have been determined with tolerable accuracy.

Millionths of a Millimetre.	
β 618·0	Darkest place in a broad band ill-defined towards the red.
596·0	Middle of a faint band.
γ 573·8	Darkest place in a broad band especially ill-defined towards the violet.
α 542·5	Middle of the darkest band in the spectrum.
δ 486·1	Middle of a band.

"The darkest place in a band in the red was found to have a wave-length of 628 millionths of a millimetre, but owing to the extreme faintness of this portion of the spectrum, little reliance can be placed upon this result. The same remark applies to the bands at the other end of the spectrum, for the edges of which—towards the violet—the wave-lengths were found to be respectively 457 and 427 millionths of a millimetre. Occasionally bands could be seen also in the central portion of the spectrum, the position of which could not be ascertained with any accuracy.

"The bands observed in the spectrum of Uranus are undoubtedly caused by the absorption of the solar rays in the atmosphere by which the planet is surrounded. By what substances this absorption is effected cannot at present be determined. It is worthy of remark that one of the bands in the spectrum of Uranus — 618 wave-length — exactly coincides with a similar one both in the spectrum of Jupiter and Saturn."

The spectrum of Neptune, as observed by Secchi, shows great similarity to that of Uranus. Vogel gives the same testimony; of the eight bands which he observed in the spectrum, the places of the three darkest were determined as follows:—

Wave-length.	
565·7 mill. m-m.	End of a broad dark band.
540·2 ,, ,,	Middle of the darkest band.
485·8 ,, ,,	Dark line, somewhat ill-defined.

PART FIFTH.

APPLICATION OF SPECTRUM ANALYSIS TO THE FIXED STARS.

APPLICATION OF SPECTRUM ANALYSIS TO THE FIXED STARS.

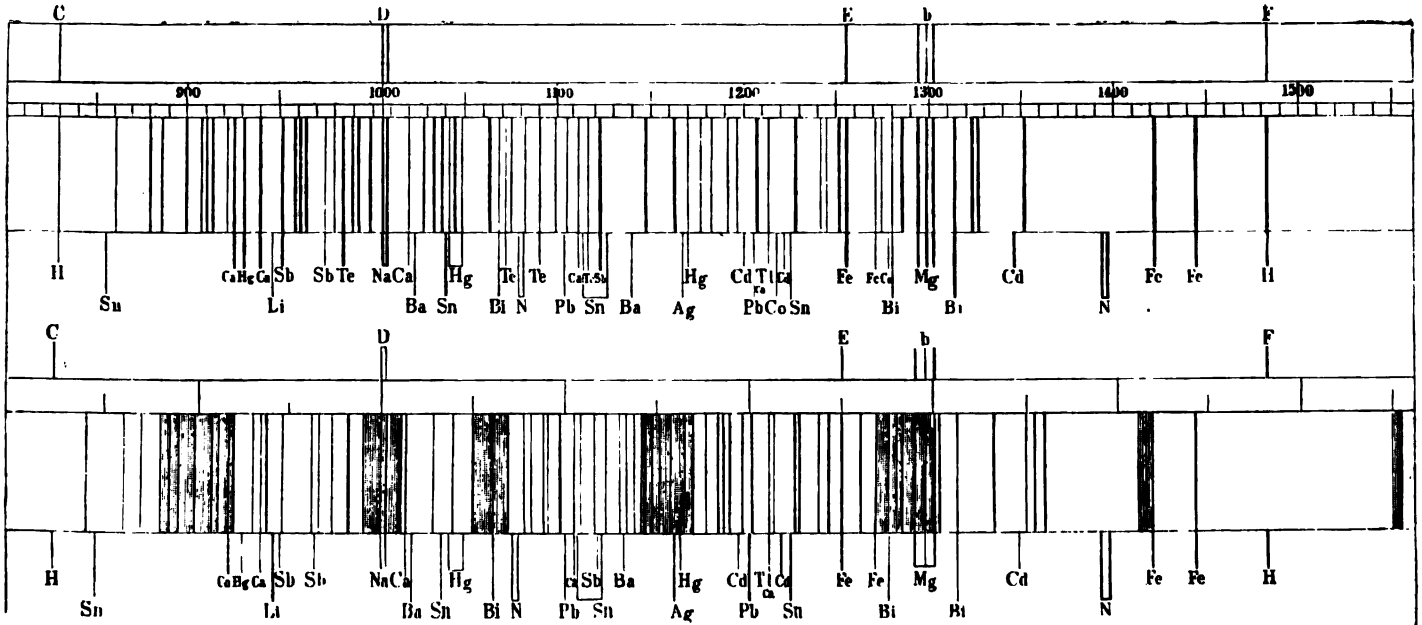
83. Spectra of the Fixed Stars.

The first to examine the spectrum of a fixed star was Fraunhofer, who in his important treatise (1814 and 1815) upon the dark lines of the solar spectrum mentions that he had also observed dark lines in the spectrum of Sirius. Subsequently, in 1823, he published similar observations upon the stars Castor, Pollux, Procyon, Capella, and Betelgeux. After a lapse of forty years the subject was again taken up by Donati, in 1862, by whom the spectra of some additional stars were obtained.

The first to study the spectra of the stars with instruments of adequate power were Huggins, Miller, and Rutherfurd. By a series of measures they determined the position of a number of dark lines in various bright stars, and by comparing these lines with the lines of terrestrial substances obtained scientific data for a conclusion as to the presence of such elements in the star examined. In Fig. 228 a map of the spectrum lines is given of Aldebaran (α Tauri) and Betelgeux (α Orionis) constructed from the observations of Huggins and Miller.

Under each spectrum are placed the bright lines of the metal with which it has been compared. These spectra of terrestrial substances appear in the spectroscope as bright lines on a dark background in the position shown in Fig.

FIG. 228.



1 Spectrum of Aldebaran (α Tauri)
2 Spectrum of Betelgeux (α Orionis) compared with Solar Spectrum and Spectra of Terrestrial Elements.

228, and in juxtaposition with the spectrum of the star, so that it can be determined with the greatest precision whether the bright lines coincide or not with the dark lines of the star.

The results of the comparison of the two stellar spectra given above (Fig. 228) with the terrestrial elements are given in the following table :—

TERRESTRIAL ELEMENTS COMPARED WITH ALDEBARAN.

COINCIDENT.	NOT COINCIDENT.			
1. Hydrogen with the lines C and F.	Nitrogen	3	lines	compared.
2. Sodium with the double D-line.	Cobalt	2	,,	,,
3. Magnesium with the triple line *b*.	Tin	5	,,	,,
4. Calcium with four lines.	Lead	2	,,	,,
5. Iron with four lines and with E.	Cadmium	3	,,	,,
6. Bismuth with four lines.	Barium	2	,,	,,
7. Tellurium with four lines.	Lithium	1	,,	,,
8. Antimony with three lines.				
9. Mercury with four lines.				

TERRESTRIAL ELEMENTS COMPARED WITH BETELGEUX.

COINCIDENT.	NOT COINCIDENT.			
1. Sodium with the double D-line.	Hydrogen	2	lines	compared.
2. Magnesium with the triple line *b*.	Nitrogen	3	,,	,,
3. Calcium with four lines.	Tin	5	,,	,,
4. Iron with four lines and with E.	Gold ?			
5. Bismuth with four lines.	Cadmium	3	,,	,,
6. Thallium ?	Silver	2	,,	,,
	Mercury	2	,,	,,
	Barium	2	,,	,,
	Lithium	1	,,	,,

The measurement and delineation of the spectrum lines of a fixed star is a very delicate and laborious work. A great advance in accuracy was therefore attained when it became possible to photograph the stellar spectra. In 1860 Huggins and Miller succeeded in photographing the most refrangible part of the spectrum of Sirius, in which, however, no dark lines were visible. It was not until the year 1876 that through the acquisition of an 18-inch reflector, supplied

with admirable clock motion, Huggins was enabled to obtain the spectra of several bright stars in which the dark lines were distinctly visible. Upon the same plate was also photographed the solar spectrum, so that a direct comparison could be instituted between the two spectra. It is scarcely necessary to remark that in photographing stellar spectra good results can only be obtained when the air is remarkably clear and tranquil.

84. The Various Types of Fixed Stars.

While Huggins and Miller were engaged in investigating about 100 of the spectra of the brightest stars, Rutherfurd

Fig. 229.

Spectrum of Sirius.

was also occupied in similar work, and to him we owe the classification of stellar spectra, for great as is the diversity they represent, they yet appeared to him to divide themselves into three groups or types. In the meantime Secchi, favoured by the clearness of an Italian sky, had observed the spectra of more than 500 stars* during the year 1867, and

* [The work of Secchi and that of Huggins and Miller are not comparable. The observations of Huggins and Miller consisted of the direct comparison in the spectroscope of the lines seen in the spectrum of a star with the bright lines of terrestrial substances, an investigation which required many months' work upon a single star, and was immensely more tedious and laborious than the micrometric measures of the principal stellar lines to which Secchi's work was mainly restricted.]

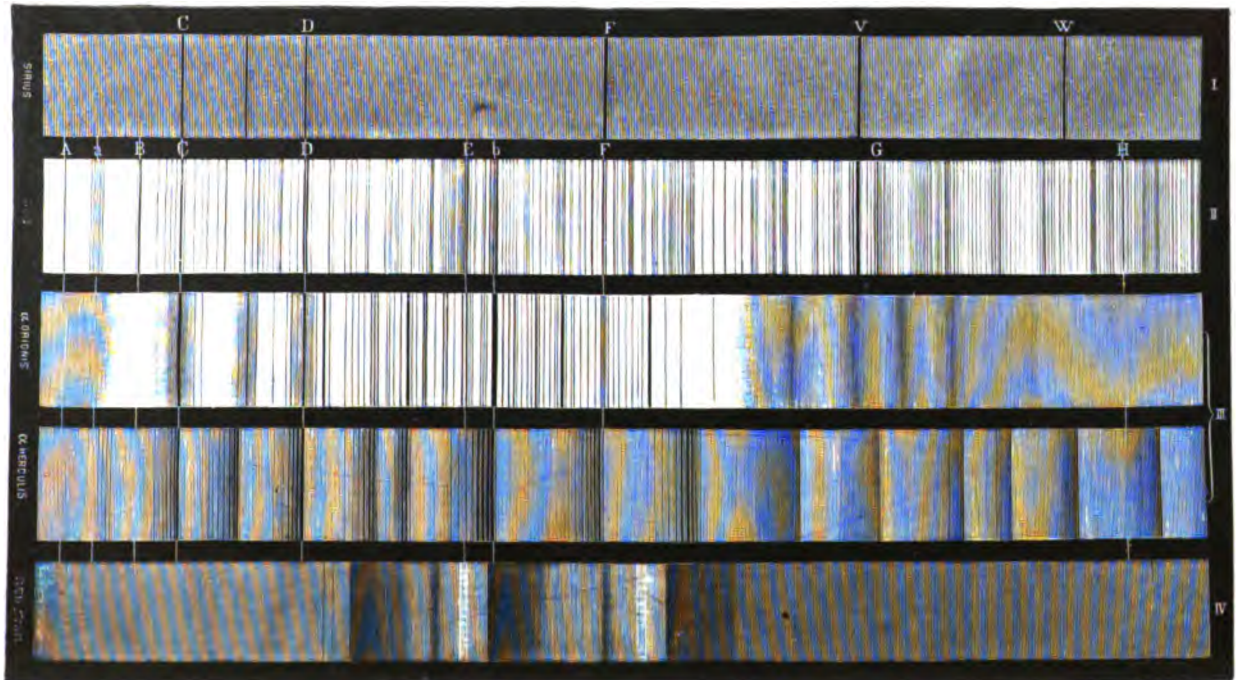
subsequently added another hundred. Aided by this mass of material, he was able to separate the stellar spectra into four principal classes or *types* under which all may be included.

The *first* type is represented by the star α Lyræ and the well-known brilliant star Sirius (Fig. 229). Most of the stars shining with a *white* light are included in this class, Vega, Altair, Regulus, Rigel, the stars of the Great Bear, with the exception of α Ursæ, etc. These are usually considered *white* stars, although they shine with a slight tinge of blue, and give a spectrum like that represented in Fig. 230, No. I. It is composed of rays of all colours, and is sometimes crossed by numerous fine lines, but always by four broad dark lines, one in the red, one in the greenish-blue, and two in the violet. All the four lines are due to hydrogen, and are in exact coincidence with the four brightest lines (Hα, β, γ, δ) composing the spectrum of terrestrial hydrogen as produced by means of a Geissler's tube. The spectra of the brightest stars of this class show also a faint dark line in the yellow, apparently coincident with the sodium line D, besides a number of still fainter lines in the green belonging to iron and magnesium.

In the smaller stars the line C in the red is difficult of observation, on account of the faintness of the light, while the line occurring in the blue is often very broad. In conformity with the blue tinge noticeable in these stars, the more refrangible parts of their spectra are relatively brighter than in other stars.

The *second* type of stars, represented by the spectrum of Arcturus (α Bootis), is that to which our sun belongs. In this class most of the *yellow* stars are included, as, for instance, Capella, Pollux, Aldebaran, α Ursæ, Procyon, etc. The dark (Fraunhofer) lines are very strongly marked in the red and in the blue portions of their spectra, but are

Fig. 230.



Types of the Fixed Stars.

almost absent in the yellow. Of this type the solar spectrum (Fig. 230, No. II.) is an example.

The stars belonging to this class are difficult to observe. The dark lines in the spectra of Capella and Pollux are extremely fine, while those in Arcturus (Plate XIII.) and Aldebaran are much broader, and more easily recognized. Aldebaran may be regarded as holding an intermediate position between the second and the third type, while Procyon forms the connecting link between the stars of the first and second type.

The dark lines in the spectrum of the second type coincide so exactly with the strongest of the Fraunhofer lines, that stars of this type may be used, as suggested by Secchi, as a standard of comparison in the investigation of other spectra, and as a correction for the instrument. This close conformity to the solar spectrum undoubtedly leads to the conclusion that these stars are composed of similar elements and possess a physical constitution in other respects analogous to that of our sun. Many of them appear to yield a continuous spectrum, but this arises from the lines being too fine to be always visible. They are generally seen in a good instrument when the air is clear and free from tremor.

Of the *third* type, which includes specially the stars shining with a *red* light, Secchi has given as an example the spectra of the stars α Orionis and α Herculis (Fig. 230, No. III.). The spectra of such stars appear like a row of columns illuminated from the side, producing a stereoscopic effect; and when the bright bands are narrower than the dark ones, the spectrum has the appearance of a series of grooves. Red stars of even the eighth magnitude have been examined by Secchi, and their spectrum found to be similar, while from white stars of the same magnitude no detailed spectrum could be obtained. Huggins remarks that with

superior instrumental power, the grooved appearances disappear, and the spectra of these stars are seen to be crossed by numerous dark lines, arranged in successive groups.

About thirty bright stars belong to this type, among which are β Pegasi, *o* (Mira) Ceti, Antares, etc.; if stars of less magnitude be included, the number will amount to about a hundred.

Secchi remarks as a peculiar characteristic of these stars that the darker lines of the spectrum separating the grooves occur in the same place in all the stars.

As a rule, the spectra of these stars resemble the spectrum of a solar spot, which has led Secchi to the conclusion that stars of the third type differ only from those of the second by the thickness of the envelope of vapour or atmosphere by which they are surrounded, as well as by the want of continuity in their photosphere; it seems possible, therefore, that these stars have spots like our sun, but of proportionally much larger dimensions.

The *fourth* type, consisting of stars not exceeding the sixth magnitude, is principally characterized by a spectrum of three bright bands separated by dark spaces; the most brilliant band lies in the green, and is in general well marked and broad; the second, much fainter, and often scarcely visible, is in the blue; while the third, in the yellow, extends as far as the red, where it separates into several divisions.

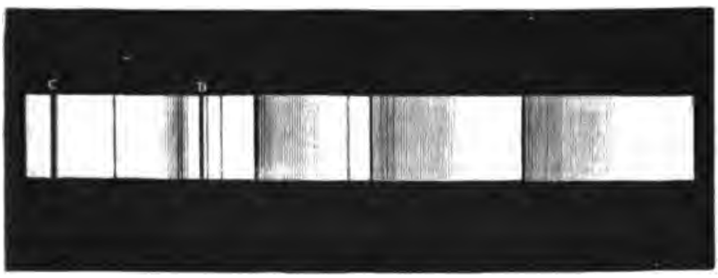
All these bright bands have this peculiarity, that they are brightest on the side towards the violet, where the light terminates abruptly, while towards the red they fade gradually away.

The spectra of this class are therefore in direct contrast to those of the third type, in which the columnar bands are not only twice as numerous, but the maximum brightness is turned towards the red, while the darker side is towards the violet. The extreme faintness of the stars of the fourth

type forbids the use of the slit, and thus precludes the examination of their spectra, in which, however, the resemblance to the spectrum of carbon is very noticeable.

A spectrum of the fourth type is given in Fig. 230, No. IV. (No. 152 of Schjellerup's catalogue). Secchi has observed about thirty of this class, the most beautiful of which are Nos. 41, 78, 132, 152, and 273 of Schjellerup's catalogue. Great variety is noticeable in their spectra, some of them exhibiting intensely bright lines, as in the case of the red star in the Great Bear (No. 152 Schj., in Fig. 230,

FIG. 231.



Spectrum of Red Star, No. 152, Schjellerup's Catalogue, after Huggins.

No. IV.), in which such two occur in the green and two in the greenish-blue.

The description of the spectra of these stars does not accord with the appearance they present to Dr. Huggins, whose diagram of the spectrum of the same red star, No. 152 of Schjellerup's catalogue (*Astronomische Nachrichten*, No. 1591) is given in Fig. 231. He compared the spectrum of the star, using a narrow slit, with the bright lines of sodium and carbon. The line marked D he found to be coincident with that of sodium. The less refrangible boundary of the first of the three principal bright bands in the spectrum of carbon is nearly coincident with the beginning of the first group of dark lines; the second of the carbon bands is less

refrangible than the second group in the star; the third band of the carbon spectrum falls on the bright space between the second and third group of dark lines in the spectrum of the star. The absorption bands are therefore not due to carbon. There is a strong line about the position of C, but this part of the spectrum is too faint to permit of comparison or micrometric measurement. The comparative relative freedom of the red part of the spectrum from dark lines is in accordance with the predominance of this colour in the star's light.

A remarkable exception to the four types above mentioned is formed by a few stars which present a *direct* spectrum of hydrogen, and may be classed, after Secchi's example, under a fifth type. The most remarkable star of this class is γ Cassiopeiæ, in the spectrum of which, according to Huggins' measurements, the bright lines $H\alpha$ (red) and $H\beta$ (greenish-blue) are visible in the places of the dark lines C and F, besides a suspected bright line in the yellow, apparently coincident with D_3. Similar spectra have been observed in the variable star β Lyræ, and in η Argo, in the spectrum of which Le Sueur with the great Melbourne telescope saw the lines C, *b*, F, a yellow line near to D (D_3?), and the most intense of the nitrogen lines as bright lines; the same phenomena have also been observed in γ Argo, as well as in temporary stars, of which more will be said hereafter.

A systematic investigation of the stars by the spectroscope has also been undertaken by D'Arrest in Copenhagen, aided by a refractor of 10½ inches aperture. Stars of the third type were discovered to abound in all parts of the heavens, and to present a striking uniformity in appearance. Among the bright stars of this class, D'Arrest was able, under very favourable circumstances, to resolve the dark absorption bands into groups of separate lines. In all these groups

the lines gradually increased in depth and sharpness towards the violet end, and, under ordinary circumstances and with a small dispersive power, gave the impression of bands sharp at one side and indistinct at the other. Of the fourth type there are no stars in the northern hemisphere bright enough to justify the hope of their yielding a similar observation, but D'Arrest is of opinion that from analogy it may be presumed that in their case also the bands are composed of lines.

One of the most interesting of the spectra is that of the red star of the eighth magnitude in R. A. 12 h. 17 m. 50 s. and D. + 1° 35·2′ (1855·0); it deserves, as D'Arrest expresses it, "a special study on account of its characteristic

FIG. 232.

Spectrum of the Star B.D. + 22°, No. 4203, after Vogel.

fragmentary character," and is so bright that it could be examined in moonlight. It consists entirely of red and yellow rays; in the green the light breaks off suddenly, and is described as a fragment of a stellar spectrum. We shall only further mention a star of the eighth magnitude, B. D. (Bonner's Catalogue) + 22°, No. 4203. In spite of the faintness of the star the spectrum is strikingly beautiful, traversed by a great number of distinctly marked bands, especially in the blue and the violet. In Fig. 232 the spectrum of this star is given, according to Vogel's measures, in which the red is to the right.

A spectrum of an entirely opposite character was found by Vogel in a star of the sixth magnitude, B. D. + 2°, No. 4703 (Schjell. Catalogue, No. 273), a drawing of which is given

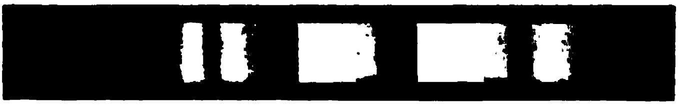
in Fig. 233, the three bands being diffused towards the violet and well defined towards the red.

The spectrum of the star Lalande 35611, bearing the No. 126 in Schmidt's catalogue of reddish-yellow stars (*Ast. Nach.*, No. 1902), where it is described as "fiery red," was discovered by Vogel (Fig. 234) to be of a fragmentary character. The blue and the violet scarcely appear, and the green and yellow are much abridged by the occurrence of broad absorption bands, defined only on the side towards the red; in the red also a faint, ill-defined band is to be noticed.

FIG. 233.

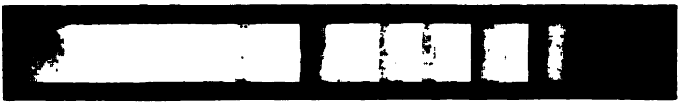
Spectrum of the Star B.D. + 2°, No. 4703, after Vogel.

FIG. 234.



Spectrum of the Star Lalande, 35611, after Vogel.

FIG. 235.



Spectrum of the Star B.D. + 8°, No. 4997, after Vogel.

Another beautiful spectrum, shown in Fig. 235, is that of a star 5·2 magnitude, B. D. + 8°, No. 4997 (Schjell. Catalogue, No. 266); it is traversed in the green and yellow with delicate bands, and has a strikingly dark band in the red.

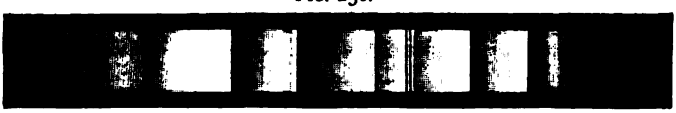
A very splendid spectrum (Fig. 236) was discovered by Vogel in the star B. D. + 7°, No. 4981, of the 5·3 magnitude. The relative intensities have been reproduced with great accuracy. The measures show a near agreement with the bands in the spectrum of *α* Herculis.

The classification of the stars to which Professor Vogel has been led by the digest of his voluminous observations differs slightly from that of Secchi. His division consists of three classes, the third including Secchi's third and fourth types.

Class I.—Including all spectra in which the metallic lines are but faintly visible, or wholly absent, and the most refrangible portion of the spectrum, the blue and the violet, especially brilliant.

(*a*) Spectra in which, in addition to the faint metallic

FIG. 236.



Spectrum of the Star B.D. + 7°, No. 4981, after Vogel.

lines, lines of hydrogen are also visible, and remarkable for their breadth and intensity. To this class belong most of the white stars, Sirius, Vega, etc.

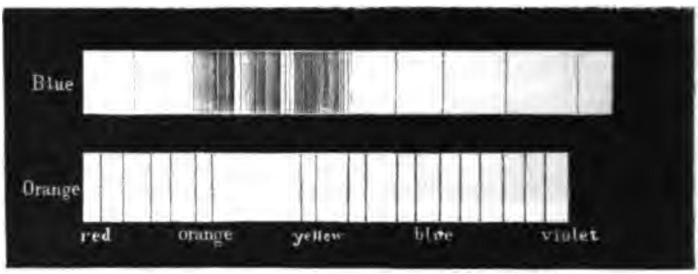
(*b*) Spectra in which individual metallic lines are only faintly visible, or are entirely absent, and the lines of hydrogen are wanting, such as β, γ, δ, ϵ, Orionis.

(*c*) Spectra in which the lines of hydrogen and the line D_3 are distinctly visible. Of this class the only representatives yet discovered are β Lyræ and γ Cassiopeiæ.

Class II. — Spectra in which the metallic lines are prominently visible, while the more refrangible portion of the spectrum is faint compared with the former class, and in the less refrangible portion of the spectrum faint bands are sometimes visible.

(*a*) Spectra in which the metallic lines are very numerous and are of sufficient brilliancy, especially in the yellow and green, to be easily recognizable. The hydrogen lines are generally prominent, but never so strikingly enlarged as in Class I., *a*. In some stars, however, these are faint, in which case the less refrangible part of the spectrum is traversed by faint bands, composed of dense groups of lines—Capella, Arcturus, Aldebaran. Under this type is to be classed among others the double star β Cygni, in which one appears of a blue and the other of an orange colour. The two spectra are given in Fig. 237; the upper one is that of

FIG. 237.



Spectra of the Component Stars of the Double Star β Cygni.

the small companion, which shines with a blue light, the lower that of the principal star, which is orange. In the latter it will be noticed that the dark lines are strongest and most numerous in the blue and violet portion of the spectrum. The orange is comparatively free from bands, and is therefore dominant. In the companion the strongest groups of lines are found in the yellow and orange, and in a portion of the red; it is therefore natural that this star should appear of a bluish tint.

(*b*) Spectra in which, besides dark lines and separate dark bands, numerous bright lines are visible. In this type may be reckoned T Coronæ, and most probably the star in

Cygnus, observed by Wolf and Rayet, and the variable star R Geminorum, although, on account of its faintness, the dark bands in the red and yellow are all that can be seen with certainty, and the dark lines are only suspected.

Class III.—Spectra in which not only dark lines, but also numerous dark bands, are visible in every part of the spectrum, and the most refrangible part is remarkably faint.

(*a*) In addition to the dark lines, bands are visible, the most prominent of which are sharply defined towards the violet, and shaded off towards the red—α Herculis, α Orionis, β Pegasi. The spectrum of α Herculis is given in Fig. 238.

(*b*) Spectra in which dark bands appear of great breadth,

FIG. 238.

Spectrum of the Star α Herculis.

the most prominent being darkest and best defined towards the red, and gradually fading away towards the violet. As yet only faint stars have been met with of this description, such as Schjell. Cat. red stars, Nos. 78, 152, 273, etc.

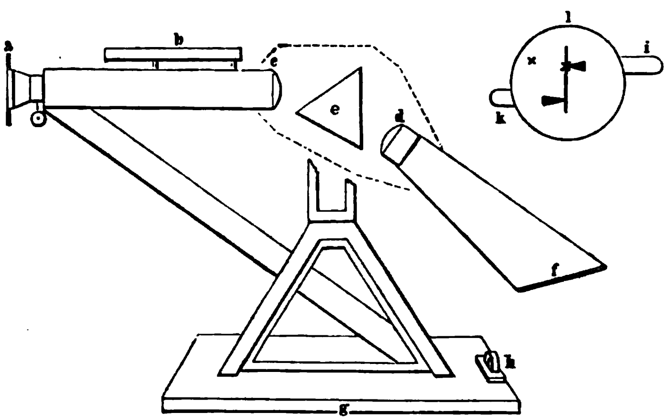
85. HUGGINS' PHOTOGRAPHED SPECTRA OF THE FIXED STARS.

It has already been mentioned that as early as 1864, photographs of some of the stellar spectra were obtained by Huggins and Miller, by the aid of a large telescope, supplied with admirable clock motion. This work has since (1879) been resumed by Huggins with instruments of greater delicacy, and the result has been a valuable series of photographs and drawings of stellar spectra. The telescope

employed is an 18-inch reflector, driven by clockwork of great excellence.

The spectroscope in connection with this instrument is of the following construction. The prism *e* (Fig. 239), of Iceland spar, has an angle of 60°, and is fixed for the minimum of deviation for the line H. The lenses *c* and *d* are of quartz. The lens of the collimator *c* is 1½ inch in diameter, and has a focal length of ten inches; the lens *d* behind the prism by which a photographic image of the spectrum is thrown upon

FIG. 239.



Huggins' Spectroscope for Photographing the Spectra of the Stars.

the plate *f* is of the same diameter, with a focal length of 6½ inches. The collimator carries the slit *a* at the further end, and has a tube *b* attached to its outer surface and parallel to its axis, by means of which, in connection with the eye-piece of the telescope, and the screw *h* in the foundation plate of the instrument, the lenses *c* and *d* may be accurately placed in the axis of the telescope.

The plate *l* of the slit of polished silver is furnished with two shutters, controlled by the handles *i* and *k*; the opening or closing of each shutter affects but one half of the length

of the slit, so that the observer can arrange whether the spectrum of the star shall be taken alone, or whether upon the same plate *f* there shall be photographed, either at the same time or subsequently, the spectrum of daylight or of some artificial source of light.

The photographic plates—gelatine dry plates—were one and a-half inch in length by half an inch broad. The photographed spectrum extended from the line G to P in the ultra-violet, and was about half-an-inch in length. The

FIG. 240.

Section of the Reflecting Telescope when the Spectroscope is in Position.

sharpness of the photographs is so great that they can be advantageously examined with a microscope of low power. Nearly fourteen lines can be distinguished between H and K.

In Fig. 240 the reflector is shown after the introduction of the spectroscope *a*, *c*. At the base of the tube lies the 18-inch mirror *b*, in the centre of which is the eye-piece, temporarily displaced by a small telescope, by the help of which the various parts of the spectroscope, and especially the slit, can be inspected. By means of a small

revolving mirror *d*, attached to the side of the telescope, the plate *c* of the slit is illuminated by yellow light, and the image of a star brought exactly into the opening of the slit.

The lines in the photograph were measured by a micrometer fitted into a microscope, and the conversion of the positions into wave-lengths was effected by a graphic process in which for the ultra-violet portion of the spectrum the maps of Cornu and Mascart were employed.

The chief results of Huggins' labours are given in Plate XIII. For the convenience of comparison, Cornu's normal solar spectrum, extending from G to O in the ultra-violet, is placed above and below. The first six spectra are those of white stars belonging principally to one type of spectrum. They are as follows: Vega, Sirius, η Ursæ Majoris, α Virginis, α Aquilæ, and α Cygni. The typical spectrum consists here of twelve strongly-marked lines ill-defined at the edges; the two least refrangible coincide with the hydrogen lines 4340 and 4101, ten millionths of a millimetre wave-length; the third line corresponds with H in the solar spectrum. The prominent line K (H_2) of the solar spectrum is represented only by a very fine line, and appears to be wholly absent both in Sirius and in η Ursæ Majoris. The relative positions of these twelve lines are pointed out by Huggins to be in a certain sense symmetrical, inasmuch as each pair of lines are in closer proximity to each other in proportion as they are more refrangible. According to the investigations of Dr. H. Vogel, four of these lines are most probably due to hydrogen; their wave-lengths in ten millionths of a millimetre are as follows:—

Measured by Vogel.	Measured by Huggins.	
3968	3968	H
3887	3887·5	α
3834	3834	β
3795	3795	γ

The nine prominent lines which are more refrangible than H are designated by Huggins with the letters of the Greek alphabet. They are as follows :—

Wave-lengths in ten millionths of a millimetre.

α 3887·5	δ 3767·5	η 3717·5
β 3834	ϵ 3745·5	ϑ 3707·5
γ 3795	ζ 3730	ι 3699

In the photographs of the typical stars a continuous spectrum extends beyond S, but no lines are visible beyond the twelfth line, wave-length, 3699 ten millionths of a millimetre. In general, as the star approaches the solar type, the twelve typical lines already mentioned become narrowed and less diffused at the edges. Finally other lines begin to appear, and those corresponding with K in the solar spectrum become broad and diffused.

In the spectrum of Vega besides the twelve lines, Huggins suspects a very fine line between H and K. The continuous spectrum extends as far as S in the ultra-violet.

The spectrum of Sirius is very similar to that of Vega, only the typical lines are somewhat broader, and more diffused at the edges. The wave-lengths have been determined by Huggins as follows :—

Wave-lengths in ten millionths of a millimetre.

*H 4340	β 3834
h 4101	γ 3795
H_1 3968	δ 3767·5
α 3887·5	

The spectrum of η Ursæ Majoris is also very similar to that of Vega, but there is some indication of fine lines in the photographed portion. The continuous spectrum extends as far as S. The following measures were taken :—

* [It must be recollected that H and H_1 in this and the following table are meant to indicate hydrogen lines and not Fraunhofer lines ; h is also a hydrogen line, but it is also a Fraunhofer line.]

29

Wave-lengths in ten millionths of a millimetre.

H 4340	H_1 3968	δ 3767·5
4087·5	α 3887·5	ε 3745·5
4137·5	β 3834	ζ 3730
h 4101	3820	η 3717·5
4121	γ 3795	ϑ 3707·5

In the spectrum of α Virginis the twelve typical lines have already begun to diminish in width, and become defined at the edges; a great number of very fine dark lines have also made their appearance. In the position of K a very fine line was suspected. The following lines were measured :—

Wave-lengths in ten millionths of a millimetre.

H 4340	H_1 3944·5	δ 3767·5
4137·5	K 3933 (probably present).	ε 3745·5
4120	3920	ζ 3730
h 4101	α 3887·5	η 3717·5
4022·5	β 3834	ϑ } doubtful.
4004·5	3816·1	
H_1 3968	γ 3795	ι }

In the spectrum of α Aquilæ not only are all the typical lines narrower and better defined than in that of Vega, but numerous other lines also are present, so that the general appearance of the spectrum has begun to approach to the solar type. The line K is prominent, but less so than H. The wave-lengths of the following lines were taken :—

Wave-lengths in ten millionths of a millimetre.

H 4230	*h* 4000 }	α 3862·5	δ 3767·5	ι 3698
4172·5	3997 }	3854	3757·5	3690
4131 }	H_1 3968	β 3834	ε 3745·5	3677·5
4120 }	K 3933	3816	ζ 3730	3656
h 4101	3915	3807·5	η 3717·5	3654
4072	α 3887·5	γ 3795	ϑ 3707·5	3637·5
4022·5				

The spectrum of α Cygni comes still nearer to the solar type. The measures are as follows :—

Wave-lengths in ten millionths of a millimetre.

H 4340	α 3887·5	γ 3795	ε 3745·5
h 4101	3862·5	δ 3767·5	ζ 3730
H_1 3968	β 3834	3757·5	η 3717·5
K 3933			

The spectrum of Arcturus differs somewhat from the foregoing, and belongs to the class in which the sun is placed. The line K is very broad and diffused, even more than the line H, and is more prominent than the corresponding line in the solar spectrum. The whole photographic spectrum appears to be traversed by lines similar to those in the solar spectrum; twenty-one of the principal lines have been measured, and their places given in the following table. Some of them are coincident with the solar lines.

Wave-lengths in ten millionths of a millimetre.

H_1 4340 { as in solar spectrum.	4064	3822·5	3662·5
	4055	3815	3657·5
4325 } doubtful,	4045	3814·5	3641
4307·5 } group G.	4043	3810	3637·5
4289	4040	3805	3625
4271	3995	3798	3610
4252·5	3980	γ 3795	3602·5
4237·5	H_1 3968	3789	3592·5
4227·5	H_2 3933	3775	3585
4214	3920	3762·5	3575
4201	3905	3755	3560
4195	3900	ε 3745·5	3551
4185	α 3887·5	3732·5	3515
4176	3881	ζ 3730	3507·5
4170	3870	η 3717·5	3504·5
4150 } probably a	3859	ϑ 3705·5	3487
4141 } group of lines.	3856	3702·5	3482
4132·5	3850	3690	3475
H_1 4112	3838	3682·5	3467
h 4099	3835	3672·5	3457
4075	3832·5		

In the spectrum of Rigel, all the typical lines are visible; they are brighter than in the spectrum of *a* Cygni, but not so

bright as in the spectrum of α Virginis. The spectrum of the star Betelgeux could only be obtained with difficulty, as after an exposure four times the length of time needed for Sirius a photograph was produced, yielding a very limited spectrum, the most distinct portion being in the neighbourhood of G. The following are the wave-lengths for the most prominent lines between G and H.

Wave-lengths in ten millionths of a millimetre.

4340	4298·5	4226	4145	4099	4025
4319	4252	4171	4132	4075	

The spectrum of Aldebaran also required a very long exposure. The part between F and H appears covered with fine lines, of which those between G and H are broad, dark, and diffused at the edges. The spectrum of Capella extends in the photograph from F to S, and resembles so closely the solar spectrum that the one could be taken for the other. The lines G, H, and K, as well as several groups of lines near H, have almost the same relative intensity and breadth as in the solar spectrum. Huggins hence concludes, that this star is in a state of development very similar to that of our sun.

Similar labours in stellar spectrum photography have been carried on by Henry Draper, by whom the spectra have been divided into two classes, those that bear a resemblance to the solar spectrum and those in which the lines are comparatively few, but of greater breadth and intensity. He concurs with Huggins in regarding the spectra of Arcturus and Capella as almost identical with that of the sun, whereas the spectra of Vega and α Aquilæ are totally different. The photographs taken by Draper have not yet been published.

86. Variable Stars.

Among the fixed stars there are several which vary in brightness as compared with neighbouring stars; their light

increases or diminishes, and in some cases even entirely disappears. The *period* of variability is the time elapsing between the two successive seasons of greatest (or least) brilliancy.

Among the variable stars, Mira Ceti offers peculiar interest, since at its maximum brightness it equals a star of the second magnitude, and at its minimum sinks down to a star of the ninth or tenth magnitude. Not less remarkable is Algol (β Persei), which for two days thirteen hours and a half shines with the brightness of a star of the third magnitude, then sinks down in three hours and a half to a star of the fourth magnitude; its light again increases, and in a similar period of three hours and a half regains its original brilliancy.

FIG. 241.

Variability of a Star according to Zöllner.

The cause of variability in these stars has not yet been discovered, and may possibly differ considerably in individual instances. In stars such as Algol, where the diminution of light is confined to a few hours, the change may be attributed to the passage of a dark planet across the face of the star, whereby part of its light is hidden from the earth. In other instances it may be explained, as Zöllner suggests, by the rotation of the star upon its axis, where the surface is of unequal brilliancy, part being obscured by the dark masses of scoriæ, produced by cooling, which would arrange themselves in a fixed order, and produce on the surface an unequal distribution of luminous matter and non-luminous scoriæ. Were this distribution to assume the form depicted by Zöllner in Fig. 241, and the bright liquid mass flowing in

the direction of the arrows *a* and *b*, or against that of the star's axial rotation, after the manner of the polar streams of our earth, to become stopped in its course by the bank of scoriæ, then the change in the brilliancy of the light, and the periodic recurrence with every revolution on its axis, would be accounted for.

It is instructive to consider how these different theories have been affected by spectrum analysis.

Huggins and Miller noticed in February 1866 that in the spectrum of Betelgeux (*α* Orionis), Fig. 228 (2), when the star was at its maximum brightness, a group of dark bands at No. 1069·5 of the scale bordered by a dark line was missing, the precise place of which had been determined by them with great care two years before. The dark shading in the diagram represents groups of fine lines, into which the apparent bands become resolved, if observed with an adequate spectroscope. Changes in this spectrum have also been observed by Secchi during a period of the star's minimum brightness. Some of the dark bands in this spectrum, as well as in that of several other red stars, Antares, Aldebaran, *o* Ceti, etc., were thought by him to be identical with certain bands in the spectrum of the nucleus of a solar spot, which led him to the conclusion that the red colour is due to the same cause that produces the absorption bands in the spectrum of a solar spot. In the spectrum of R Geminorum, during its period of maximum brightness, Secchi observed a *bright* hydrogen line, a phenomenon he also noticed in the variable star *β* Lyræ. The spectrum of Algol, belonging to the first type, remains unchanged during the period of diminished brilliancy, which led Secchi and Vogel to suppose that in this instance the periodic variation in light is caused by the passage of a dark body between the star and the earth.

Vogel has given some attention to the spectra of variable

stars. In R Lyræ (Fig. 242) he discovered a very beautiful spectrum similar to that of *α* Herculis. The spectrum of R Leporis was observed on December 11th, 1873, when the star was near its maximum brightness, and a broad band was noticed both in the yellow and the green. The most refrangible part of the spectrum was full of absorption bands, while the red and yellow were tolerably intense.

Like Secchi, Vogel noticed in the spectrum of R Geminorum *bright* lines, but their appearance was not confined entirely to the period of maximum brightness, "so that it must not be assumed that the increase of brightness in the star results from an outburst of the gases, the characteristic lines of which appear in the spectrum." Vogel is of opinion, moreover, that the bright lines in this spectrum

FIG. 242.

Spectrum of the Variable Star R Lyræ, after Vogel.

are neither hydrogen nor the D-lines. The positions of the bright lines in *β* Lyræ have been accurately determined by Vogel, and their respective wave-lengths are 587·5, 485·9, 434·0. The first line is somewhat more refrangible than D, and coincides with the line D_3, which was first noticed in the prominences. The other two belong to hydrogen. Besides these lines some fainter ones were suspected. One of them is situated between D and C; the others are probably coincident with the lines *b* (magnesium) of the solar spectrum. The bright lines in the spectrum of *β* Lyræ consequently appear to be coincident with the lines of the solar chromosphere. This is also the case with the star *γ* Cassiopeiæ.

Attention had been drawn by Wolf and Rayet to three

faint stars in Cygnus, in the spectra of which bright lines were visible. Vogel found that in these spectra the bright lines stood out with remarkable brilliancy from the faint continuous spectrum, and determined their position with accuracy. In the spectrum of the first star, 8·5 magnitude B. D. + 35° No. 4001 (Æ 20 hrs. 5 min. 31 sec. D. + 35° 49·5′ for 1875), Vogel observed four bright lines (579·5 very faint, 567·5 only occasionally visible, 536 very bright, 468 very bright and broad, diffused towards the violet). In the spectrum of the second star, 8·0 magnitude B.D. + 35° No. 4013 (Æ 20 hrs. 7 min. 12 sec. D. + 35° 49·6′), four bright lines are easily recognised, but their respective intensity is not the same as in the other star. A remarkable dark band extends from wave-length 565 to 554 millionth of a millimetre. In the third star, 8th magnitude B.D. + 35° No. 3956 (Æ 20 hrs. 9 min. 51 sec. D. + 35° 16·8′), the four bright lines are also visible, and the spectrum appears to be bounded towards the red by the first bright line. The position of the bright lines is identical in the spectra of the three stars, but they differ greatly as to their relative intensity. The colour of these stars is a point not yet decided; according to Vogel, the first two are yellowish, the third a yellowish white; further observations will be necessary before it can be established that these stars are variable.

87. New or Temporary Stars.

Among the variable stars may also be reckoned those which from time to time, but only at exceedingly long intervals, have suddenly shone brightly in the heavens and disappeared again after a longer or shorter interval; such stars always excite the greatest wonder and interest, not only from the rarity of their appearance, but also from the mighty convulsions which they announce. According to Humboldt,

only twenty-one such stars have been recorded in the space of two thousand years, from 134 B.C. to 1848 A.D., the most remarkable of which were that observed by Tycho Brahe (1572) in Cassiopeia, which surpassed both Sirius and Jupiter, and even rivalled Venus in brilliancy, but disappeared after seventeen months, without leaving a trace visible to the naked eye,* and that seen by Kepler (1604) in the right foot of Ophiuchus, which excelled Jupiter, but did not quite equal Venus in brightness, and at the end of fifteen months was visible only by aid of the telescope. A characteristic peculiarity of these temporary stars is that their increase in brilliancy is in general very rapid, while the diminution in light is slow and irregular.

Fortunately for science, phenomena of this nature have occurred since the application of spectrum analysis to the examination of the heavenly bodies. On the night of the 12th of May, 1866, a new star, brighter than one of the second magnitude, was observed at Tuam, by Mr. John Birmingham, in the constellation Corona Borealis. On the following night it was seen by Courbebaisse at Rochefort, and was observed a few hours earlier at Athens by Schmidt, who expressly declares that the new star could not have been visible before eleven o'clock on the night of the 12th of May, as he had been observing R Coronæ, and could not have failed to notice the new star had it been then visible. On the same night (13th of May) the light of the star sensibly decreased, and by the 16th of May it had become reduced to the fourth magnitude. Its brightness then waned somewhat rapidly: it decreased from 4·9 on the 17th to 5·3 on the 18th, and from 5·7 on the 19th to 6·2 on the 20th, till by the end of the month it had become a star of the ninth magnitude.

* The telescope was not invented until thirty-seven years after this date.

That the star was not a new one is evident from Argelander's *Durchmusterung des nördlichen Himmels*, where it is to be found as No. 2765 in + 25° declination. Argelander had observed the star on the 18th of May, 1855, and on the 31st of March, 1856, and on both occasions had classed the star as between the ninth and tenth magnitudes.

Huggins was informed by Birmingham of his discovery on the 14th of May, and was thus enabled on the 15th inst. to examine with Miller the spectrum of this star when it had not fallen much below the third magnitude. The result of this investigation is as follows.

The spectrum of the star was very remarkable, and showed clearly that there were two distinct sources of light, each

FIG. 243.

Spectrum of the Temporary Star T Coronæ Borealis. (15th May, 1866.)

producing a separate spectrum. The compound spectrum (Fig. 243) is evidently composed of two independent spectra superposed, the one a continuous spectrum crossed by dark lines similar to that given by the sun and other stars, the other consisting of *four bright* lines, which from their great brilliancy stand in bold relief upon the dark background of the first spectrum.

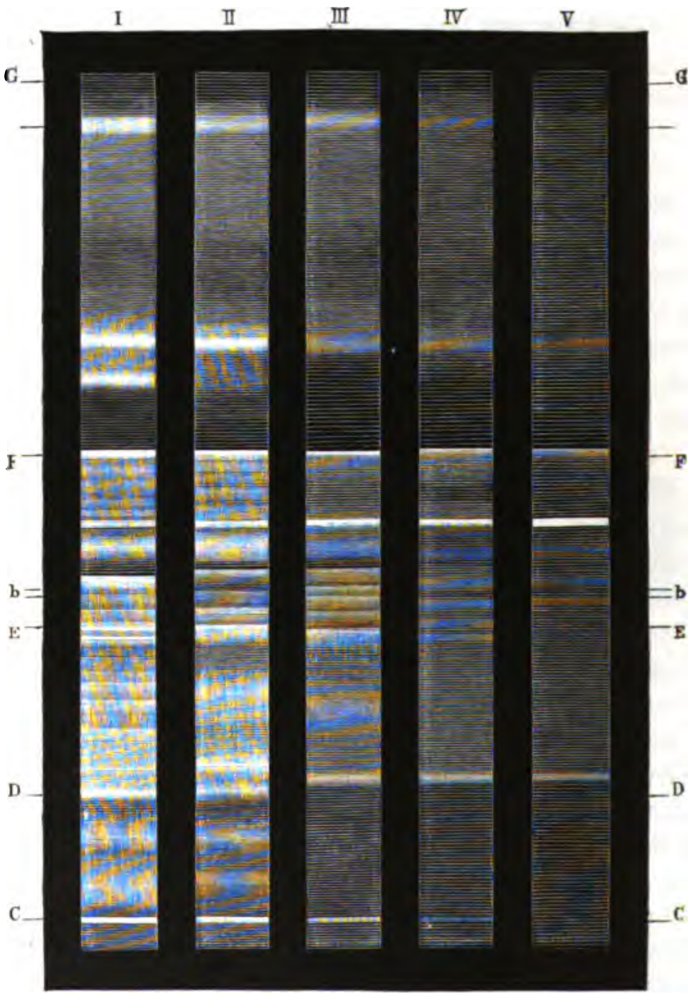
The continuous spectrum traversed by dark lines shows the presence of a photosphere of incandescent matter probably solid or liquid, which is surrounded by an atmosphere of cooler vapours, giving rise by absorption to the dark lines. This absorption spectrum contains two strong dark bands of less refrangibility than the D-line ; from these a group of fine

lines extends almost to D, while one fine line is coincident with D. So far the spectrum is analogous to that of the sun and the stars; but there are also present bright lines, indicating a second source of light, which is undoubtedly an intensely luminous gas.

Huggins compared the spectrum of the star on the 17th of May with the spectrum of hydrogen produced by the induction spark through a Geissler tube, and found that the strongest of the stellar lines 2 was coincident with the greenish-blue line of hydrogen. Apparently, also, the line 1 in the red coincided with the $H\alpha$-line, but owing to the faintness of the line, the coincidence could not be ascertained with the same degree of certainty. The star is now about the tenth magnitude. According to Vogel, its spectrum is continuous, differing little from that of any other star.

On the 24th of November, 1876, another new star was observed at Athens by Schmidt, to the east of β Cygni. It was then of the magnitude of 3·5, and of a deep gold colour, almost red. The spectrum as observed by Backhouse, Copeland, Cornu, Lohse, Secchi, and Vogel was again one of bright lines, analogous to that of the star of 1866. Vogel commenced his investigations on the 5th of December, and describes the spectrum as peculiar in character, brilliant, but traversed by numerous dark bands, in which several bright lines were to be noticed of which the most conspicuous was in the red, and the next one in the borders of the green and blue. The intensity of this brilliant spectrum soon diminished; after three months only a portion remained, and that extremely faint. The loss of intensity was not uniform in all the colours; the blue and the violet faded quicker than the green and yellow. The red portion, which at first was faint and traversed with broad dark bands, soon disappeared, so that a solitary bright line in the red was left. In the first stage a dark band in the green was very prominent, after-

FIG. 244.



8th Dec., 1876. 14th Dec. 1st Jan., 1877. 2nd Feb. 2nd March.

Spectrum of the New Star of 1876, after Vogel.

wards a broad dark band in the blue. With the exception of those in the red, the bright lines at first scarcely exceeded in brilliancy the continuous spectrum; afterwards, as the star lost light, they became more prominent, especially the lines identified by measures with Hα and Hβ of hydrogen, and subsequently a line of which the wave-length was 499. Another of the prominent lines was the one in all probability Hγ hydrogen. The line wave-length 499 coincides with the brightest line of nitrogen, and is the same as the one observed in nebulæ. It remained the longest visible as the spectrum faded, and exceeded in brightness the hydrogen lines, of which the one in the red was the first to visibly diminish in brilliancy. A diffused bright line at wave-length 580, and a similar one at wave-length 467, were observed,—nearly coincident with a dense group of lines in the spectrum of air—together with others in the neighbourhood of *b* and E, the exact position of which could not be determined. Several drawings of the spectra were made by Vogel, which have been reproduced; it will be seen, on reference, to Fig. 244, to which stage of the star's appearance the drawing refers.

At the end of October 1877 Vogel was successful in again observing the spectrum of the star, although it was then reduced to the tenth magnitude. The spectrum consisted only of one bright line—wave-length 499 millionths of a millimetre—on either side of which an exceedingly faint continuous spectrum was to be traced. A later observation on February 18th, 1878, records the same phenomenon, so there can be no doubt that an important change had taken place in the character of the spectrum. The fact of a star yielding a continuous spectrum to be changed in the course of a year into a single bright line is at present wholly unexampled. The observations by Vogel are fully confirmed by those of Lohse.

The cause of such a sudden outburst in a star may well excite our wonder. There can be no doubt that the phenomenon has no reference to the process of the creation of a star, but only to some change in its constitution by which its luminous power is affected. Of the nature of this change nothing is known. The sudden brilliancy might be attributed to the encounter of two cosmical masses, whereby their momentum is changed into molecular motion resulting in an increase of temperature and a consequent increase in light. It might be also supposed that by some internal catastrophe a mass of hydrogen gas is developed which, when rendered combustible by the presence of some other element, might occasion the outburst of light. Finally, the suggestion of Lohse might be adopted, that by the process of cooling a fixed star becomes enveloped by an atmospheric envelope which absorbs so much of its light as greatly to reduce its brightness as seen from the earth. When through the continued action of radiation the temperature is further reduced to the point necessary for the chemical combination of the chief elements present, the heat and light developed by such a process would render the star suddenly visible to a great distance.*

In discussing the conclusions to be deduced from the observations hitherto made upon temporary stars, Vogel remarks, "For those versed in the study of stellar spectra the phenomenon of a star yielding a spectrum of bright lines is one of the highest interest, well worthy of the most earnest consideration. For although in the chromosphere of our sun, at the sun's edge, many bright lines are to be distinguished, yet if a minute star-like image of the sun be formed and examined with a spectroscope, only dark lines are perceptible. It is generally supposed that the

* [This is very improbable, and may be rejected for very cogent reasons.]

bright lines visible in some of the stellar spectra are due to gases which have burst out from the interior of the luminous mass at a temperature higher than the surface, in the same way that bright lines of hydrogen are sometimes visible in the spectrum of a solar spot caused by the eruption of incandescent hydrogen from the interior of the sun over the cooler surface of the spot. This is not, however, the only explanation. It may be assumed that the glowing gases by which a star is surrounded, as in the case of our sun, are at a lower mean temperature than that of the nucleus, although relatively extremely high.

"By the first supposition it seems to me impossible to imagine the phenomena enduring any length of time. The gas escaping from the central mass would impart some of its heat to the cooler surface, thereby raising its temperature until the difference between the heat of the incandescent gas and that of the surface is no longer sufficient to produce the bright lines, and consequently they disappear.

"This theory is admirably suited to explain the sudden apparition of so-called *new* stars in the spectra of which bright lines are visible, and of their speedy disappearance, or at least marvellous diminution in brightness if as a further explanation the hypothesis stated below is accepted. When the phenomenon is permanent in character the second theory seems to me the most admissible; it appears to me probable that stars such as β Lyræ, γ Cassiopeiæ, and others in the spectra of which the lines of hydrogen and the line D_3 appear with slight variation bright upon a continuous spectrum, must be surrounded by a comparatively extensive atmosphere composed of hydrogen and of the substance represented by the line D_3.

"On the subject of new stars I call to mind a hypothesis suggested by Zöllner in reference to the valuable observations made by Tycho upon the star that bears his name,

before the field of physical astronomy had been so greatly enlarged through the introduction of the spectroscope.

"Zöllner, as is well known, supposes that by the continual process of radiation the chilled masses, which in the case of the sun are known as solar spots, gradually augment till finally the whole surface is covered with a cooler stratum of vastly diminished luminous power. Through any sudden rent in this darkened stratum the incandescent mass enclosed must of necessity burst forth, and cause luminous spots of greater or less extent. To an observer at a distance such an outburst would appear as the sudden apparition of a *new* star. That in some cases the development of light might be extreme would follow from the circumstance that all the chemical combinations which had taken place on the surface under the influence of a lower temperature would be again set free by the sudden eruption, and this chemical action would necessarily be accompanied by a development of heat and light. The outburst of light would therefore not be due merely to those portions of the surface rendered luminous by the outflowing incandescent central mass, but also to a species of *combustion* caused by the contact of the cooler elements in chemical combination.

"The hypothesis advanced by Zöllner as to the gradual development of the heavenly bodies has been sustained in all important points by the results of spectrum analysis. The various stages of cooling are to be recognised in the spectrum, and in some of the fainter stars evidence exists that in the atmosphere by which the incandescent mass is surrounded chemical combinations could already be formed and maintained. The spectroscopic observations made upon the two new stars of 1866 and 1876 give no countenance in any particular to the hypothesis that the stars are in reality new.

"The very bright continuous spectrum from which at

first the bright lines are scarcely detached cannot be wholly explained by the assumption that violent outbursts of gas from the interior re-illumine the darkened surface, but it is in full agreement with the supposition that the sudden brilliancy is the effect of combustion. Were this of short duration, the continuous spectrum would rapidly decrease in brilliancy up to a certain point, as was the case in the star of 1876, while the bright lines in the spectrum formed by the incandescent gases, which issue from the interior in enormous quantities, would remain much longer visible.

"The connection between the fading of the star and the cooling of its surface is evidently shown by the examination of the spectrum. The violet and blue portions were the first to diminish in intensity, and the absorption bands traversing the spectrum became gradually broader and darker."

It must not be forgotten that light, though an extremely quick messenger, yet occupies a certain time in coming to us from a star. The speed of light is about 185,000 miles in a second; the distance of one of the nearest fixed stars (α Centauri) is about sixteen billion miles, so that light takes about three years to travel from this star to us. The great physical convulsion observed in the star in Corona in the year 1866 was therefore an event which had taken place long before, at a time when spectrum analysis, which has yielded such interesting results, was yet unknown.

88. Influence of the Proper Motion of the Stars in Space upon their Spectra.

In § 78 the principle was unfolded by which spectrum analysis enables us to discover the movement of a star in space, through the displacement of its spectrum lines. It was shown that the displacement of any of the spectrum

lines towards the violet indicated that the star was approaching us; a displacement towards the red showed, on the contrary, that the star was receding from us, and the amount of this displacement indicated the rate of motion.

On entering on this kind of investigation, Secchi directed his telescope to Sirius, and brought the dark F-line in exact coincidence with the direct image of the star; he then turned his instrument to another fixed star of the same type in which the F-line was also visible, and observed it narrowly to ascertain whether this line were also coincident, or showed some displacement. His instrument did not, however, prove adequate to such delicate observation, and the results obtained were not decisive.

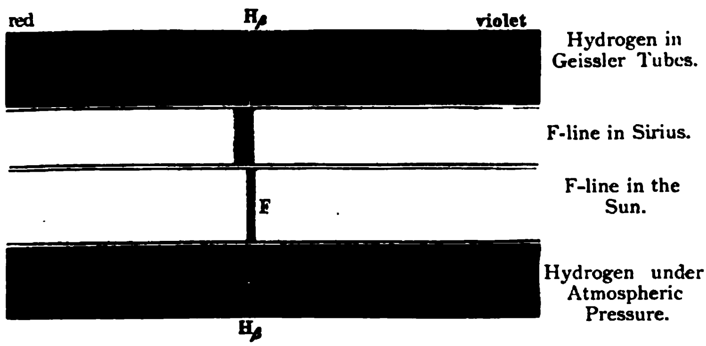
Fig. 245.

Spectrum of Sirius as observed by Huggins.

By the aid of more delicate instruments, and an apparatus better adapted for such measurements, Huggins was more fortunate. Having established that a strongly marked dark line in the spectrum of Sirius (Fig. 245) was the hydrogen line $H\beta$, he compared it successively with the $H\beta$-line of the hydrogen spectrum formed from a Geissler tube, with the Fraunhofer F-line of the solar spectrum, and also with the $H\beta$-line of hydrogen when under atmospheric pressure. Fig. 246 shows the position of these three lines in relation to each other and to the line in Sirius. While the comparison lines coincide exactly, the *line in Sirius is displaced a little towards the red.* As this line in Sirius appears broader than the bright hydrogen line $H\beta$, which is always the case

with this line when the gas is subjected to some pressure, it became of importance to determine whether the expansion of the hydrogen line Hβ under pressure takes place unsymmetrically or equally on both sides. Huggins found, as was subsequently confirmed by Lockyer and Frankland, in 1869, that when the hydrogen line Hβ becomes expanded from an increase in the density of the gas, this widening always takes place equally on both sides, and the middle of the line preserves its position. It is probable that the expansion of the line in Sirius may arise from a similar cause, but at the

FIG. 246.



Displacement of the F-line in the Spectrum of Sirius.

same time there cannot be a doubt *that the whole line suffers a displacement towards the red as compared with the terrestrial hydrogen line.*

This displacement, as measured by Huggins, amounted to about a quarter of the distance between the two D-lines. The difference between the wave-lengths of these two D-lines is 4·36 millionths of a millimetre; the displacement of the F-line in the spectrum of Sirius corresponds therefore to an *increase in the wave-length* of 0·109 (or 0·15) millionth of a millimetre. If the velocity of light be taken to be 185,000 miles in a second, and the wave-length of the

light at the line F to be 486·50 millionths of a millimetre, then the observed displacement of the line in Sirius indicates a recession of Sirius from the earth at the rate of $\frac{185000 \times 0 \cdot 109}{486 \cdot 50}$, or 41·4 miles in a second.

The earth has evidently some share in this motion. The direction of the earth's motion in its orbit changes every instant, and there are two points separated 180° one from another, in which the direction of motion coincides with the line of sight from Sirius. In the one place the earth is approaching the star, in the other it is receding from it, while in the two other points of the orbit 90° from the former positions, the earth's motion is at right angles to the star's line of sight, and has therefore no influence on the refrangibility of the rays.

At the date of these observations the earth was moving away from the star at the rate of 12 miles in a second; there remains therefore for the proper motion of Sirius a movement of recession from the earth amounting to 29·4* miles in a second, and if the probable advance of the sun in space be taken into account, this motion would be reduced to about 26 miles.

Similar observations have been undertaken by Huggins on *a* Canis Minoris, Castor, Betelgeux, Aldebaran, and some other bright stars.

Vogel and Lohse have since been occupied in this field of research, and employed the following method of observation. A Geissler tube filled with hydrogen was introduced inside the telescope so as to be in contact with the cone of light coming from the object examined, and in such a position that the length of the tube was perpendicular to the slit, and the spectroscope directed in a position parallel to the diurnal motion. By a concave cylinder lens the width of the spec-

* [In 1884 Mr. Christie found that the direction of motion of Sirius has changed.]

trum was regulated in front of the slit. The spectrum of a star occupied but a narrow belt in the field of view, while the bright lines of the gas spectrum extended across the whole field of view of the telescope. In this way the bright lines of the comparison spectrum were seen on *either* side of the band-like stellar spectrum. Vogel has learnt by experience that comparisons made on *one side* only—such as can be obtained by a so-called comparison prism—are not sufficient for very delicate measurements, and may even give rise to considerable error in the estimation of coincidence of any two lines.

FIG. 247.

Spectrum of Sirius with the F-line.

By means of such an apparatus under very favourable conditions of atmosphere Vogel and Lohse succeeded, on the 22nd of March, 1871, in observing the displacement of the three hydrogen lines in the spectrum of Sirius as compared with the lines Hα, Hβ, and Hγ in the spectrum of the Geissler tube, and by the micrometer determined this amount with respect to the F-line to be 0·15 $\pm$ 0·025 millionths of a millimetre of a wave-length. The lines in the spectrum of Sirius were much enlarged, which greatly increased the difficulty of the observation. In Fig. 247, a portion of the spectrum of Sirius is given, which includes the F-line. In the lower figure the bright hydrogen line is seen to be not in coincidence with the central and darkest part of the broad F-line. In the stellar spectrum this line, though broader

than the C-line, is exceeded in breadth by the Hγ-line. In all the three lines the displacement towards the red end of the spectrum was distinctly visible.

The spectrum of Procyon was also examined, and a displacement observed of the three hydrogen lines Hα, Hβ, Hγ, towards the red end of the spectrum. The observations of Capella were rendered especially difficult from the faintness of the F-line and the existence of several delicate lines in its neighbourhood. There appeared to be a displacement towards the red end of the spectrum, but of smaller amount than in the two other stars.

Systematic observations upon the proper motion of the stars are now carried on at Greenwich by means of an instrument of great dispersive power devised by Mr. Christie.

In the following table the collateral results are given up to 1881. The motion when receding from the earth is indicated by the sign +, when approaching the earth by —. The figures placed after ± indicate the probable error in the mean value. For comparison the results obtained by Huggins are also given, as well as a brief description of the lines.

Name of Star.	Motion in Miles.	Number of Nights Observed.	Huggins' Results.	Remarks.
α Andromedæ .	− 33±4·2	9	−	F broad, ill-defined
β Cassiopeiæ . .	+?	1		F broad, diffused
γ Pegasi	− 46	3	−?	F diffused
α Cassiopeiæ .	+?	2		b_1
γ Cassiopeiæ .	− 27	2	+	F broad, ill-defined
β Andromedæ .	+12	2		F well-defined
β Arietis . . .	− 14	2		b_1 broad, very black
α Piscium . .	− 36	2		F narrow, well-defined
γ¹ Andromedæ .	− ?	2		b_1
α Arietis . . .	− 21	4		b_1 well-defined
α Ceti	− 34 ?	1		b_1, b_4 channelled spectrum
β Persei . . .	−	1		F dark, sharp
α Persei . . .	+25	2		F faint, diffused

Name of Star.	Motion in Miles.	Number of Nights Observed.	Huggins' Results.	Remarks.
ζ Persei . . .	–	1		b_1 very faint
Aldebaran . .	$+20\pm2{\cdot}0$	7	+?	b_1 very well-defined
Capella . . .	$+27\pm4{\cdot}5$	9	+	b_1 well-defined, F well-defined
Rigel	$+18\pm1{\cdot}9$	9	+15	F very well-defined
γ Orionis . .	$-1\pm1{\cdot}4$	4		F very well-defined
β Tauri . . .	−18	3		F broad, diffused
δ Orionis . . .	$+4\pm6{\cdot}1$	6		F faint, narrow
ϵ Orionis . . .	$-22\pm10{\cdot}3$	6		F faint, narrow
ζ Orionis . . .	+9	3		F faint, narrow
κ Orionis . .	−1	2		F well-defined
α Orionis . .	$+21\pm1{\cdot}8$	8	+22	b_1, b_2 channelled spectrum
β Aurigæ . .	−7	3		F broad, ill-defined
γ Geminorum .	+2	2		F broad, well-defined
Sirius	$+20\pm2{\cdot}4$	10	+18 to 22	F broad, diffused
β Canis Minoris	−?	1		F broad, diffused
Castor	$+25\pm4{\cdot}2$	8	+23 to 28	F very broad. diffused
Procyon . . .	$+24\pm3{\cdot}9$	10	+	F broad, ill-defined
Pollux	$-26\pm4{\cdot}0$	13	−49	b_1 well-defined, F faint, well-defined
α Hydræ . . .	+39	2		b_1
ϵ Leonis . . .	−14	3		b_4 well-defined
Regulus . . .	$+26\pm2{\cdot}4$	8	+12 to 17	F broad
γ^1 Leonis . .	$-38\pm4{\cdot}6$	5	−	b_1
β Ursæ Majoris	$+28\pm4{\cdot}7$	8	+17 to 21	F very dark, broad, and ill-defined
α Ursæ Majoris	−27	2	−46 to 60	b_1, F faint
δ Leonis . . .	−28	2	+	F broad, dark [away
θ Leonis . . .	+?	1		F very dark, broad, fading
χ Ursæ Majoris	+?	1		F very dark, broad, ill-defined
β Leonis . . .	+34	4	+	F broad
γ Ursæ Majoris	$+17\pm2{\cdot}7$	6	+17 to 21	F very dark, broad, ill-defined
δ Ursæ Majoris	+10	2	+17 to 21	F very dark, broad, ill-defined
γ Virginis . .	+37	4		F weak, fading away
ϵ Ursæ Majoris	$+16\pm3{\cdot}7$	5	+17 to 21	F broad, fading away
δ Virginis . .	+?	1		b_4 columnar spectrum
α Canum Venat.	−?	1		F very dark, broad, and well-defined
ϵ Virginis . .	−28	2		b_1
Spica	$+4\pm4{\cdot}0$	7	+	F narrow, well-defined
ζ Ursæ Majoris	+18	3	+17 to 21	F very dark, broad, ill-defined
η Ursæ Majoris	−8	3	+	F broad, fading away
η Bootis . . .	−?	1		b_1 sharp
Arcturus . . .	$-33\pm2{\cdot}8$	14	−55	b_1 very sharp, D_2 dark, F well-defined
γ Bootis . . .	−?	1		F broad
ϵ^2 Bootis . . .	$-7\pm3{\cdot}6$	7	−	b_1, b_4 well-defined

Name of Star.	Motion in Miles.	Number of Nights Observed.	Huggins' Results.	Remarks.
β Ursæ Minoris	+26	2		b_1 faint
β Libræ . . .	+11	3		F faint, well-defined
α Coronæ . .	+40±4·6	7	+	F very dark, broad, fading away
α Serpentis . .	–?	1		b_4 columnar spectrum
ε Serpentis . .	+35	2		F broad
γ Herculis . .	–?	2		F fading away
η Draconis . .	+3	3		b_1 very faint
β Herculis . .	–?	2		b_1 very faint
ζ Herculis . .	+25	2		b_1
ζ Draconis . .	–22	2		F fading away
α Herculis . .	–31	2		b_4 columnar spectrum
β Draconis . .	+20	4		b_1, b_4 very faint
α Ophiuchi . .	+17?±7·1	9		F very diffused
ξ Draconis . .	+?	1		b_1 very faint
γ Draconis . .	–17±2·0	5		b_1, b_4 very sharp
α Lyræ . . .	–34±2·4	14	–44 to 54	F very dark, broad, fading away
γ Lyræ . . .	+9	2		F broad. fading away
ζ Aquilæ . . .	–16?±16·5	5		F very broad, fading away
δ Aquilæ . . .	–?	1		F broad
β Cygni . . .	–18	3		b_1 sharp
γ Aquilæ. . .	–14	3		b_1 sharp
δ Cygni . . .	–17±3·6	5		F fading away
α Aquilæ. . .	–13?±11·7	9		F very broad, fading away
γ Cygni . . .	–15±3·4	9	–	b_1, b_4 sharp, F well-defined
α Delphini . .	+22	2		F very broad
α Cygni . . .	–43±4·4	9	–39	b_1 faint, F well-defined
ε Cygni . . .	+18	4		b_1, b_4
ζ Cygni . . .	–?	1		b_1 uncertain
α Cephei . . .	–?	1		F very dark, well-defined
β Cephei . .	+?	1		b_1 uncertain
ε Pegasi . . .	–15±2·5	10		b_1, b_2, b_4 sharp
η Pegasi . . .	–21	2		b_1
Fomalhaut . .	?	2		F sharp
β Pegasi . . .	+19	3		b_1, b_4 columnar spectrum
α Pegasi . . .	–34±5·9	7	–	F broad, sharp

PART SIXTH.

RESULTS OF THE SPECTROSCOPIC INVESTIGATION OF NEBULÆ AND CLUSTERS.

RESULTS OF THE SPECTROSCOPIC INVESTIGATION OF NEBULÆ AND CLUSTERS.

89. Spectra of Nebulæ and Clusters.

In a telescope of moderate power stellar clusters and faint nebulous forms reveal themselves against the dark background of the sky, which might be taken at first sight for clouds, but which, by their unchanging forms and persistent appearance, are proved to belong to a special order of heavenly bodies. Sir William Herschel was able, with his gigantic telescope, to resolve many of these nebulæ into clusters of stars, possibly vast groups of individual suns. But many nebulæ were not thus resolvable, and some even resisted a power of 6,000, which suggested to this astute investigator the theory that, besides the many thousand *apparent* nebulæ which reveal themselves as a complete and separate system of worlds, there are also thousands of *real* nebulæ composed of primeval cosmical matter of the Universe.

Lord Rosse, by means of a telescope of his own construction of six feet aperture, was able to resolve into clusters of stars many of the nebulæ not resolved by Herschel; but there were still revealed to the eye, thus carried further into space, new nebulæ beyond the power even of this gigantic telescope to resolve.

Telescopes failed, therefore, to solve the question whether the unresolved nebulæ are portions of the primeval matter out of which the existing stars have been formed, or whether they exist as a complete and separate system of worlds.

That which was beyond the power of the most gigantic

telescopes has been accomplished by the spectroscope. This insignificant but exquisitely sensitive instrument has established the existence of nebulæ as isolated bodies in space, and that these bodies are luminous masses of gas.

The largest and most irregular of all the nebulæ is that in the constellation of Orion. It is situated rather below the central three stars of that magnificent constellation. Near

Fig. 248.

Nebula of the Form of a Sickle.

the middle of the nebula are four bright stars, forming a trapezium. The nebulous matter surrounding these stars is of mottled appearance, and stretches out in long curved streaks. Professor Henry Draper, of New York, has lately succeeded in taking an admirable photograph of this nebula. The instrument employed was an eleven-inch refractor, power 180, and an exposure of 137 minutes.

A somewhat later, but much more perfect set of photographs has been taken by Mr. Common, of Ealing, with his three-foot reflector, in less than forty minutes. By the kind permission of Mr. Common, a reproduction of one of these admirable photographs is allowed to appear as the frontispiece to this work.

Nebulæ of less irregularity in form are the great Magellanic clouds in the southern hemisphere, visible to the naked

FIG. 249.

Spiral Nebula. (H. 1173.)

eye, and one of which exceeds by five times the apparent size of the moon.

The interest aroused by these irregular and nebulous forms is further increased by the phenomena of the spiral nebulæ with which the giant telescopes of Lord Rosse and Mr. Bond have made us further acquainted. As a rule, there streams out from one or more centres of luminous matter innumerable curved nebulous streaks, which recede from the centre in a

spiral form, and finally lose themselves in space. Fig. 248 represents a nebula in the form of a sickle or comet tail (Herschel, No. 3239), Fig. 249 a complete spiral (H. 1173), and Fig. 250 the most remarkable of all the spiral nebulæ situated in the constellation Canes Venatici* (H. 1622).

The transition state from the spiral to the annular form is shown in such nebulæ as the one represented in Fig. 251 (H. 604); and they then pass into the simple or compound annular nebula, of which a type is given in Fig. 252.

FIG. 250.

Spiral Nebula in Canes Venatici. (H. 1622.)

In Fig. 253 a representation is given of a compound annular nebula (H. 854), with very elliptic rings and bright nucleus.

According as the ring has its surface or its edge turned towards us, or according as our line of sight is perpendicular or more or less obliquely inclined to the surface of the ring, its form approaches that of a circle, a ring, an ellipse, or

* [Mr. Common's photographs of this nebula show that it has not a strictly spiral form.]

even a straight line. Nebulæ of this latter kind are represented in Fig. 254 (H. 1909), and in Fig. 255 (H. 2621). When an elliptical ring is extremely elongated, and the minor axis is much smaller than the major one, the density and brightness of the ring diminishes as its distance from the central nucleus increases; and this takes place to such a degree sometimes, that at the ends of the major axis, it ceases to be visible, and the continuity appears broken. The nebula has then the appearance of a double nebula, with a central spot as represented in Fig. 256 (H. 3501) and Fig. 257 (H. 2552).

FIG. 251.

Spiral Nebula. (H. 604.)

FIG. 252.

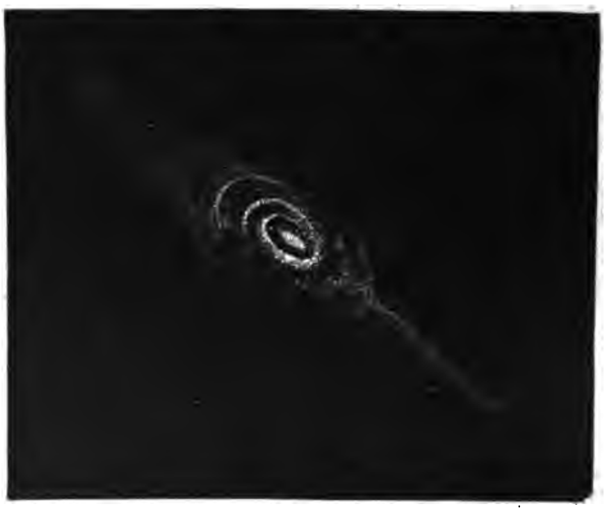
Annular Nebula in Lyra.

Those nebulæ which have edges tolerably sharply defined, and are in the form of a circle or slight ellipse, would appear to belong to a much higher stage of development. From their resemblance to those planets which shine with a pale or bluish light, they have been called *planetary* nebulæ. In form, however, they vary considerably, some of them being spiral and some annular. Some of these planetary nebulæ are represented

in Figs. 258 (H. 838), 259 (H. 464), and 260 (H. 2241). The first has two central stars or nuclei, each surrounded by a dark space, beyond which the spiral streaks are disposed; the second has also two nuclei, but without clearly separable dark spaces; the third is without any nucleus, but shows a well-defined ring of light.

The highest type of nebulæ are certainly the stellar nebulæ, in which a tolerably well-defined bright star is

FIG. 253.



Nebula with Several Rings. (H. 854.)

surrounded by a completely round disc, or faint halo of light, which in some instances fades away gradually into space, and in others terminates abruptly. Figs. 261 (H. 2098) and 262 (H. 450) exhibit the most striking of these very remarkable stellar nebulæ; the first is surrounded by a system of rings like Saturn, with the thin edge turned towards us; the second, a star of the eighth magnitude, is not nebulous, but surrounded by a bright luminous atmosphere perfectly concentric.

FIG. 254.

Elliptical Annular Nebula. (H. 1909.)

FIG. 256.

Double Nebula. (H. 3501.)

FIG. 257.

Annular Nebula with Centre. (H. 2552.)

FIG. 255.

Elongated Nebula. (H. 2621.)

FIG. 258.

Planetary Nebula with two Stars. (H. 838.)

After thus passing in review the facts concerning nebulæ revealed to us by the telescope, we may turn our attention

to the additional facts made known to us by the spectroscope, which extend even to the nature and constitution of these remote heavenly bodies. It will be well here to remind

FIG. 259.

Planetary Annular Nebula with two Stars. (H. 464.)

FIG. 260.

Planetary Nebula. (H. 2241.)

the reader that the character of the spectrum not only indicates the substance that emits the light, but also its physical condition. If the spectrum be a *continuous* one, consisting of rays of every colour or degree of refrangibility,

FIG. 261.

Planetary Nebula. (H. 2098.)

FIG. 262.

Stellar Nebula. (H. 450.)

then the source of light is either a *solid* or *liquid* incandescent body;* if, on the contrary, the spectrum be composed of *bright lines* only, then the light comes from *luminous gas;*

* [Or gas in a high state of condensation.]

finally, if the spectrum be continuous, but crossed by *dark* lines interrupting the colours, it is an indication that the source of light is a solid or liquid incandescent body, but that the light has passed through an atmosphere of vapours at a lower temperature, which by their selective absorption have abstracted those coloured rays which they would have emitted had they been self-luminous.

When Huggins first directed his telespectroscope in August 1864 to one of these objects, a small but very bright nebula (H. 4374), he found, to his great surprise, that the spectrum (Fig. 263), instead of being a continuous coloured band such as that given by a star, consisted only of *three bright lines.*

This one observation was sufficient to solve the long-

FIG. 263.

Spectrum of Nebula. (H. 4374.)

vexed question, at least for this particular nebula, for such a spectrum could only be produced by a substance in a state of gas. The light of this nebula, therefore, was emitted neither by solid nor liquid incandescent matter, nor by gases in a state of extreme density, as may be the case in the sun and stars, but by luminous gas in a highly rarefied condition.

In order to discover the chemical nature of this gas, Huggins followed the usual methods of comparison, and tested the spectrum with the Fraunhofer lines of the solar spectrum, and the bright lines of terrestrial elements. A glance at Fig. 264 will show the result of this investigation. The brightest line (1) of the nebula coincides exactly with the brightest line (N) of the spectrum of nitrogen, which

is a double line. The faintest of the nebular lines (3) also coincides with the bluish-green hydrogen line Hβ, or, which is the same thing, with the Fraunhofer line F in the solar spectrum. The middle line (2) of the nebula was not found to coincide with any of the thirty terrestrial elements with which it has been compared; it lies not far from the barium line Bα, but is not coincident with it.

The question why all the characteristic bright lines of these gases are not visible in the spectrum of the nebula has occupied the attention of Huggins, Frankland, and Lockyer.

FIG. 264.

Spectrum of Nebula compared with the Solar Spectrum and Spectra of some Terrestrial Elements.

It has been noticed by all these observers, that when hydrogen or nitrogen enclosed in a Geissler tube has been made luminous by the electric spark and is held at some distance from the slit of the spectroscope, not only does the double line of nitrogen appear as a single line, but the remaining bright lines of both gases entirely disappear, with the exception of those lines which are visible in the spectrum of the nebula.

The experiments of Frankland and Lockyer had proved that the spectrum is somewhat affected by temperature and pressure, but Fievez has lately shown that the intensity of

the light is also an element of great importance. He made the experiment of varying the intensity of the light examined by a spectroscope without altering the conditions of temperature or pressure. Under these circumstances as the intensity of light diminished, the lines of hydrogen disappeared, first the line $H\beta$, then $H\alpha$, while the line $H\gamma$ remained visible to the last.* Now this line is the one found in most of the nebulæ. Experiments with the spectrum of nitrogen yielded precisely similar results. They seem to justify the supposition expressed by Huggins, that the missing lines of nitrogen and hydrogen have become extinguished during the enormous distance the light has travelled in coming from the nebula to us.

The early experiments of Huggins showed that in respect of the gases hydrogen and nitrogen, when the intensity of their light was diminished in any way, as by the removal of the spark from the slit, or by the interposition of screens of neutral tint glass, the line in each gas coincident with one of the lines of the nebula was the last to disappear. At present we have no certain knowledge of the state of things in the nebulæ, whether the visibility of one line only of the gases composing them (in a few nebulæ a second line of hydrogen near G is seen) is due to the diminution of their light by the imperfect transparency of interstellar space through which the light has passed, or to their original feeble luminosity. By direct comparison with the light of a candle Huggins found the intrinsic brilliancy of nebula No. 4628 to be equal to $\frac{1}{1508}$, of the annular nebula in Lyra to $\frac{1}{6032}$, and of the Dumb-bell nebula to $\frac{1}{19604}$ of the intensity of the flame of a sperm candle burning 160 grains per hour. These results would be affected by any interstellar absorption, should such exist.

Besides the spectrum containing these three bright lines,

* [Fievez' experiments were by no means new.]

the nebula gave also a very faint continuous spectrum (Fig. 263) of scarcely perceptible width, which from its nature could proceed only from the diffused light of a faintly glowing nucleus, either solid or liquid, or from faintly luminous matter in the form of a cloud of solid or liquid particles.

All planetary nebulæ yield the same spectrum; the bright lines appear with a certain relative intensity in the spectroscope, although the nebulæ may not be brighter in the heavens than stars of the ninth magnitude.* The reason of this is that the light of the stars is spread out into a continuous spectrum, while that of the nebula remains concentrated into a few lines; the principle is identical with that by which the spectra of the solar prominences have been observed in sunlight simultaneously with the greatly subdued spectrum of daylight.

The characteristic difference between the spectrum of a planetary nebula and that of a fixed star has been successfully employed by Professor Pickering, of Cambridge, Mass., as a means of detecting such planetary nebulæ as from their small size are undistinguishable even in the largest telescopes from minute fixed stars. The plan adopted was to introduce into the 15-inch refractor between the eye-piece and the object-glass a small direct-vision spectroscope, and to observe with the telescope in a fixed position. As the ceaseless stream of stars passed through the field of view, it was easy to distinguish between the spectra of coloured lines presented by the stars and the nearly monochromatic light of the nebulæ. By the first experiment with this method four new planetary nebulæ were discovered.

* [Though the lines of the nebulæ are distinctly visible under favourable circumstances, the terrestrial lines to be compared with them must not be brilliant; when an induction spectrum is used, the light has frequently to be diminished in intensity by a piece of neutral tint glass.]

Fig. 265 is the planetary annular nebula in Aquarius, from a drawing by Lord Rosse. It gives a spectrum of three bright lines, one of which is due to nitrogen, and another to hydrogen.

FIG. 265.

Planetary Annular Nebula in Aquarius, with Spectrum.

The nebula (H. 4964) represented in Fig. 266 is of a spiral character; it is remarkable from its spectrum containing four bright lines, two of which indicate hydrogen and one nitrogen.

FIG. 266.

Spiral Nebula (H. 4964), with Spectrum.

In the spectrum of the annular nebula in Lyra (H. 4447), Fig. 267, Huggins at first observed only one bright line, that of nitrogen. When the spectroscope is so directed to the nebula that the slit cuts straight through it, the bright line appears to be composed of two brilliant lines corresponding to the upper and lower segments of the ring. These two lines are united by a small band, which shows that the faint inner portion of the nebula is of the same substance as that of the surrounding ring. In the powerful instrument at Bothcamp the spectrum of this nebula showed three lines, of which two were measured, while the position of the third could only be estimated on

account of its faintness, but Vogel is fully persuaded of its coincidence with $H\beta$. The two brighter lines could be distinguished in the faint centre of the nebula.

The great nebula of Orion has been the subject of numerous spectroscopic investigations. Its spectrum consists of three very conspicuous bright lines, one of which indicates nitrogen and another hydrogen. According to Vogel, the three lines are visible in every part of the nebula without variation in intensity. They appear upon a dark background without any trace of a continuous spectrum. The wave-lengths of these lines as measured by Vogel are respectively 500·3, 495·8, and 486·1 millionths of a millimetre. Recently a fourth line has been seen by Lieut.-Colonel Herschel in India, by Lord Rosse, and also by Professor Winlock, of Harvard Observatory—the same line which Huggins had before observed in the nebula H. 4964 (Fig. 266), and which belongs apparently to hydrogen. This line has also been seen by Vogel. Possibly other extremely faint lines may be present in this spectrum, which could only be seen by instruments of much greater power than any now in use.

FIG. 267.

Annular Nebula in Lyra with Spectrum.

These researches are of too recent a date for the results as yet to be conclusive. It may, however, be stated that in the spectrum of the nebula in Draco (H. 4374), first examined by Huggins in 1864, the line 2 was brighter than 3, while Vogel in 1871 found line 3 fully as bright or even brighter than 2, and D'Arrest again in the following year observed line 2 to be unquestionably brighter than 3. This seems to indicate that certain changes take place in the condition of the light emitted by the nebula.

In ordinary spectroscopic observations of nebulæ the visible rays are alone regarded. If the invisible rays beyond G and H are to be dealt with, recourse must be had to photography, which, as in the case of the stars, is sensitive to the ultra-violet rays, and thus completes the spectrum. By means of the apparatus described in § 85, Huggins succeeded, on March 7th, 1882, in photographing the spectrum of the nebula in Orion. The length of exposure amounted to forty-five minutes, but the slit was somewhat wider than he had employed in photographing the stellar spectra. The photograph shows distinctly the four lines characteristic of the nebula, besides a strong line in the ultra-violet, of which the wave-length is 373·0 millionths of a millimetre. In the opinion of Huggins this coincides with the line ζ of the typical photographic spectrum of the brightest

Fig. 268.—Photographed Spectrum of Nebula in Orion, by Huggins.

white stars, and belongs possibly to hydrogen. In Fig. 268

the photograph of the spectrum of the nebula of Orion is given, and above it that of a white star. In the spectrum of the nebula the lines $H\gamma$ and $H\beta$ are narrow, and sharply defined, while in the spectrum of the white star they are broad and diffused.

Almost simultaneously with Huggins, Professor Draper was employed in photographing the spectrum of the nebula of Orion. He made the remarkable discovery of two bright spots in the nebula, immediately in front of the trapezium, which give a continuous spectrum. At these spots there must therefore be either gas under a very great pressure, or a liquid or solid self-luminous substance ; but it is certain that no bright stars are to be found there. In Draper's photograph the hydrogen line $H\gamma$ is prominent and sharply defined, while the line near *h* is very delicate, and there are besides indications of extremely fine lines in the violet. The line ζ, which Huggins obtained, is absent in Draper's photograph. The explanation offered by Draper of its absence is either that the slit of the spectroscope was directed on different portions of the nebula, or that the telescopes employed were of different construction, that of Draper being a refractor, while that of Huggins was a reflector—perhaps also by a variation in the process of developing the photograph.*

As a result of his observations, Huggins divides the nebulæ into two groups :

1. The nebulæ giving a spectrum of one or more bright lines.

2. The nebulæ giving a spectrum apparently continuous.

About a third of the sixty nebulæ observed belong to the first group; their spectrum consists of one, two, or three bright lines, a few showing at the same time a very narrow, faint, continuous spectrum. They are as

* [This last supposition is quite untenable.]

follows;—the numbers refer to Sir John Herschel's general catalogue:

No. 4373	37 H. IV.	No. 4214	5 Σ.
" 4390	6 Σ.	" 4403	17 M.
" 4514	73 H. IV.	" 4572	16 H. IV
" 4510	51 H. IV.	" 4499	38 H. VI.
" 4628	1 H. IV.	" 4827	705 H. II.
" 4447	Annular nebula in Lyra	" 4627	192 H. I.
" 4964	18 H. IV.	" 385	76 M.
" 4532	Dumb-bell	" 386	193 H. I.
" 1189	Nebula in Orion	" 2343	97 M.
" 2102	27 H. IV.		

Clusters and nebulæ showing a continuous spectrum without lines:

No. 4294	92 M.	No. 4230	13 M.
" 4244	50 H. IV.	" 4238	12 M.
" 116	Nebula in Andromeda	" 4244	50 H. IV.
" 117	32 M.	" 4256	10 M.
" 428	55 Andromedæ	" 4315	199 H. II.
" 826	2 H. IV.	" 4357	11 M.
" 4670	15 M.	" 4437	11 M.
" 4678	18 H. V.	" 4441	47 H. I.
" 105	151 H. I.	" 4473	Auwers 44
" 307	156 H. I.	" 4885	56 M.
" 575	156 H. I.	" 4526	2081 h.
" 1949	81 M.	" 4625	52 H. I.
" 1950	82 M.	" 4600	15 H. V.
" 3572	51 M.	" 4760	207 H. V.
" 2841	43 H. V.	" 4815	53 H. I.
" 3474	63 M.	" 4821	233 H. II.
" 3636	3 M.	" 4879	251 H. II.
" 4058	215 H. I.	" 4883	212 H. I.
" 4159	1945 h.		

It is interesting to inquire how far and in what manner the classification of nebulæ as given by the spectroscope is in accordance with the classification made by the telescope.

This information is given in the following table, drawn up by the present Earl of Rosse, by whom a revision has been undertaken of all the observations made with his father's

great telescope of such of the nebulæ and clusters as had been examined by Huggins.

	Continuous Spectrum.	Spectrum of Lines.
Clusters	10	0
Resolved, or apparently resolved	10	0
Resolvable, or apparently resolvable	5	6
Blue or green, no resolvability	0	4
No resolvability apparent	6	5
	31	15
Not observed through Lord Rosse's telescope	10	4
Total	41	19

Half of the nebulæ giving a continuous spectrum have been resolved into stars, and about a third more are probably resolvable; while of those yielding a spectrum of lines, not one was resolved by the late Lord Rosse. Considering the extreme difficulty attending investigations of this kind, there is scarcely any doubt that there is a complete accordance between the results of the telescope and spectroscope. Those nebulæ, therefore, giving a continuous spectrum are clusters of actual stars, while those giving a spectrum of bright lines must be regarded as masses of luminous gas, of which nitrogen and hydrogen form the chief constituents. Although the spectroscopic investigation of nebulæ, notwithstanding the advance it has made, is still young, yet the results that have been already obtained give it an important place in all questions connected with the history of the Universe. The ingenious conclusions arrived at by the elder Herschel from the revelations made by his powerful reflectors, as to the existence of nebulous masses of so-called cosmical vapour, in which these masses were regarded as the germs out of which suns and solar systems might be evolved, have received strong support from the investigations of the spectroscope, and have been elevated from the realm of pure speculation to that of deductions based on scientific data.

PART SEVENTH.

RESULTS OF THE SPECTROSCOPIC INVESTIGATION OF COMETS AND METEORS.

RESULTS OF THE SPECTROSCOPIC INVESTIGATION OF COMETS AND METEORS.

90. Comets.

We propose now to direct our attention to comets, a class of heavenly bodies singular in their aspect and transient in their appearance, remarkable alike for the mystery of their constitution and the peculiar nature of their orbits. These, though exceedingly diverse, have the sun for a common centre. While some comets have been found to move in closed orbits round the sun with a regular period of revolution, others seem suddenly to enter our system from the regions of space, and retreat again to be seen no more. The periodic comets are as follows:—

Comet.	Period.	Distance from the Sun. Perihelion.	Distance from the Sun. Aphelion.
	Years.	Mil s.	
Encke's	3⅓	289 Millions.	350 Millions.
Winnecke's	5½	69 ,,	501 ,,
Brorsen's	5⅜	55 ,,	516 ,,
Biela's	6¾	78 ,,	564 ,,
Faye's	7½	156 ,,	543 ,,
Halley's	76⅙	52 ,,	3157 ,,

While these comets have but a short period, there are others, such as the comets of 1858, 1811, and 1844, the calculated periods of which amount respectively to 2,100, 3,000, and 100,000 years, or, to speak more accurately, their period of revolution is too vast for calculation. Great

diversities are also presented in the position the sun occupies in their orbits. While Encke's comet is twelve times nearer the sun at its perihelion than at its aphelion, other comets, with an orbit extending beyond Jupiter, approach so close to the sun as almost to graze the surface. The comet of 1680 approached the sun to within one-sixth of his diameter, and its temperature was estimated by Newton to have exceeded by 2000 times that of melted iron.* The comet of 1843 was so near the sun at its perihelion that in consequence of its brilliant incandescence, it was seen in broad daylight.

Most comets exhibit a central disc more or less bright, called the *nucleus*, which is surrounded by a fainter cloudy

FIG. 269.

July Comet on 3rd July, 1861.

or nebulous envelope, the *coma;* the nucleus and coma form the head of the comet. In powerful telescopes the nucleus of a comet becomes so nearly reduced to a point that its existence seems after all a matter of doubt. In almost all comets visible to the naked eye there streams out from the head a fan of light—the tail, which varies greatly in width and length as well as in form, being sometimes straight, sometimes curved, but almost always turned away from the sun. The tail occasionally divides into two or more portions,

* [This was a speculation founded on the law that Newton had promulgated regarding the relation between temperature and radiation. The sun itself cannot be by any means 2,000 times the temperature of molten iron, and, therefore, it would be incapable of raising the temperature of the comet to that degree of heat.]

an instance of which is given in Fig. 269, showing the aspect of the comet of July 1861; in the comet of 1844 the tail consisted of six streamers.

Comets that are too small or too remote to be seen by the unassisted eye are usually without a tail, and differ little in appearance from a nebula, an example of which is given in Fig. 270, representing Donati's comet as first seen on the 2nd of June, 1858.

FIG. 270.

Donati's Comet on 2nd June, 1858.

Comets are transparent in every part, and cause no refraction in the light of the stars seen through them. Bessel observed a star through Halley's comet within a few seconds from the centre of the nucleus, without any diminution in the star's light being noticeable, and Struve made a similar observation with regard to Biela's comet. From accurate measures taken of the position of the stars it was ascertained that no effect of refraction was produced by the comets.

FIG. 271.

Donati's Comet on 5th October, 1858.

Similar observations were made with respect to Donati's comet of 1858 (Fig. 271), and the comet of July 1861 (Fig. 272). Close to the head of the former, where the tail was about 54,000 miles in thickness, Arcturus was seen to shine with undiminished brightness; while in both comets a number of stars appeared of their full brilliancy even through

32

a much thicker portion of the tail. The nucleus of the comet of 1828 was about 528,000 miles in diameter, and yet Struve saw a star of the eleventh magnitude through it, a fact which seems to justify the conclusion that a comet has no influence to dim the light of a star.

The nebulous envelope, or coma, is also subject to changes in form and size, according as the comet approaches or recedes from the sun. It might be expected that the coma on approaching the sun would expand by the extreme

FIG. 272.

July Comet on 2nd July, 1861.

heat; but exactly the reverse has often been observed. In Encke's comet, for instance, on its appearance in 1838, the diameter of the coma on the 9th of October was 285,480 miles; on the 25th of the same month it was 122,616 miles; on the 23rd of November it measured 39,302 miles; and on the 17th of December it was only 3,038 miles.

The persistent position of the tail away from the sun is clearly shown in a drawing by Professor Müller, given in Fig. 273. In the map the position of the sun is marked on the lower line for the 27th of September, and the 8th and 14th

of October, and these places are connected by straight lines with the places of the comet for those dates. The tail appears always curved, with the convex side towards the direction of the comet's motion, and this edge is the most sharply

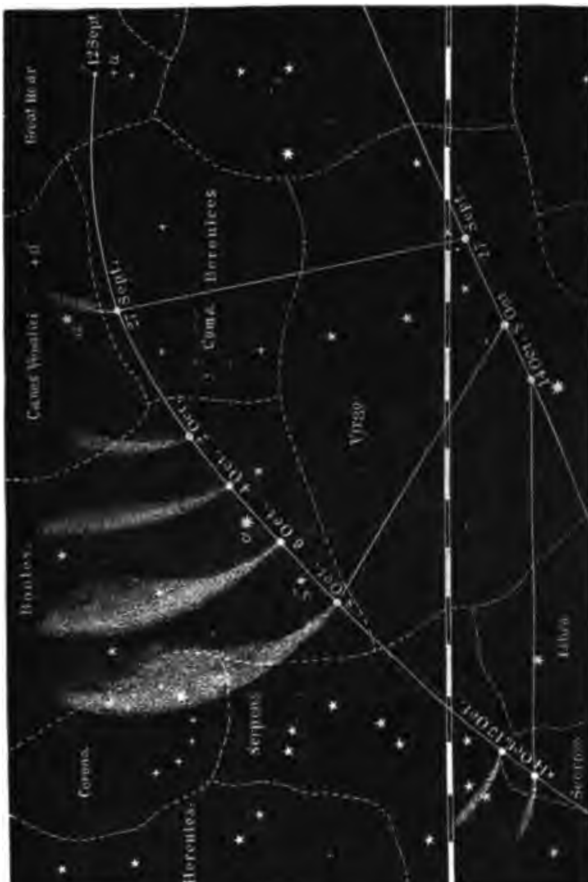


Fig. 273.

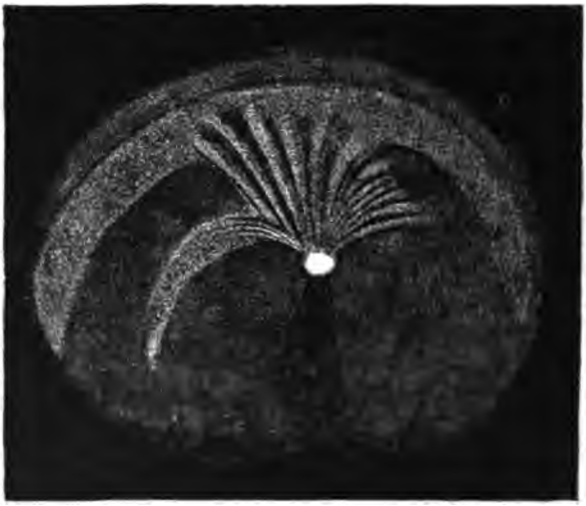
Orbit of Donati's Comet.

defined, as if some resisting medium had impeded the advance of the tail.

As a comet approaches the sun, the tail is observed to increase, whence it may be concluded that the sun contributes

essentially to its formation, and produces a separation of material particles from the head of the comet. The length of the tail is rarely less than 500,000 miles, and in some cases it extends as far as 100,000,000 or 150,000,000 miles. The breadth of the tail of the great comet of 1811 at its widest part was nearly 14,000,000 miles, while its length was 116,000,000; and that of the second comet of the same year extended to even 140,000,000 miles. Notwithstanding these

Fig. 274.



Head of the Comet of 1861, as observed by Secchi on 30th June.

enormous dimensions, the formation of the tail takes place in a very short space of time, often in a few weeks, or even days.

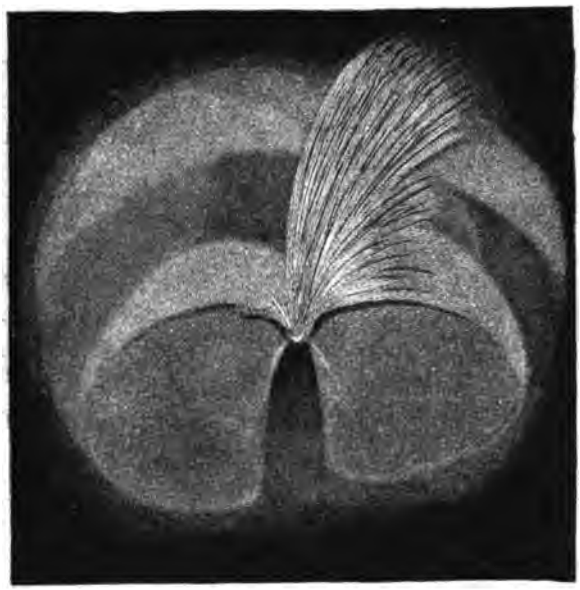
The influence exercised on the formation of the tail by the sun was shown in the comet of 1680, which at its perihelion travelled at the rate of 1,216,800 miles in an hour, and put forth a tail 54,000,000 miles in length in two days.

It is very probable that our earth actually passed through

the tail of the magnificent comet of July 1861, on the 30th of June of that year, but no indication of such a contact was evinced. This comet suddenly appeared in the northern heavens on the day previous; the telescopic appearance of the head as observed by Secchi is shown in Figs. 274 and 275.

The comet of 1776 passed among the satellites of Jupiter

FIG. 275.



Head of the Comet of 1861, as observed by Secchi on 1st July.

without disturbing their position in the slightest degree. But this was not the case with the comet, for the influence of the planet was so great on its small mass as to force it to take an entirely new orbit, which it now accomplishes in about twenty years.

Upon the approach of a comet to the sun a process begins in the nucleus presenting the appearance, in a telescope, of an

emission of luminous matter. This phenomenon was first noticed by Heinsius in the great comet of 1744, and afterwards by Bessel in Halley's comet (1835), and by him carefully observed during several days. It assumed the form of an outspread fan, and its central line was pointed at first nearly in the direction of the sun, but soon this direction changed, and it alternately vibrated to the right and left of the radius vector, so that the issuing cone of light exhibited an oscillating or revolving motion. The outflow from the nucleus appeared to be most vigorous when directly pointed towards the sun, and always decreased in energy in proportion as it departed from the radius vector, ceasing entirely when the cone of light was on the point of reversing its oscillation. It was noticed further by both observers that the outstreaming matter, after advancing a certain distance towards the sun, bent round in an outward direction, rushing away from the sun with great velocity on either side of the nucleus. The phenomena were identical so far that the outflow of the comet's substance towards the sun occasionally takes place at periodic intervals. In the comet of 1862, the first stream of vapour had scarcely subsided when a second burst forth, and when this seemed to be exhausted the first reappeared. In the comet of 1858 (Donati) and that of 1861 a number of such luminous streams appeared, thrust out towards the sun, which on reaching a certain point were bent round in an opposite direction till they reached the tail by a number of elongated arches in the manner shown in Figs. 274 and 275 from Secchi's drawings, in which the sharp outlines are a little exaggerated.

The rapidity with which the expelled matter rushes away from the sun to form the tail is often extraordinary. From careful measures of the tail of the great comet of 1811 Olbers found that it extended over 120,000 geographical miles, and that this enormous distance was

travelled by the attenuated substance of the comet in a little more than eleven days.

We must now consider the remarkable phenomenon of a comet becoming separated into two parts, each pursuing an orbit of its own. Such an occurrence happened to Biela's comet while under observation in the year 1845. When observed on the 26th of November, it appeared as a faint nebulous spot, nearly circular, increasing in density towards the middle. On the 19th of December it was rather more elongated, and ten days later it had become divided into two separate cloudy masses of equal dimensions, each furnished with a nucleus and tail, and for three months one followed the other at a distance of one-tenth, subsequently one-fifth of the moon's diameter. In conformity with the period of the comet, they appeared again in August 1852, but the distance between them had much increased, and from 154,000 miles, it had now reached 1,404,000 miles. The return of this comet was expected in the year 1859, and again in 1866, when, from its close proximity to the earth's orbit, it must have been visible. Notwithstanding the most diligent search, however, the comet could not be found, and it would seem that it has ceased to be a comet, and has passed into some other form of existence.

In considering the physical constitution of comets it is important first to ascertain whether they are self-luminous or shine by the reflected light of the sun. Their transparency has been explained by the supposition that they are either composed of a gas in a state of extreme rarefaction, or of numberless small solid particles, individually separated by intervening spaces through which the light of a star can pass without obstruction, and which, held together by mutual attraction, move through space like a cloud of dust. It is also not impossible that comets without a nucleus are masses of gas at a white heat, of similar constitution to the nebulæ.

The first to examine comets spectroscopically was Donati, at Florence; he observed the spectrum of the comet I., 1864, and found it to consist of three *bright* lines.

Tempel's comet was observed in January 1866 by Secchi and Huggins, who found that it yielded a *continuous* spectrum exceedingly faint at the two ends; a bright line, situated about half-way between *b* and F of the solar spectrum, was seen by both observers, and two additional faint ones were noticed by Secchi.

In the years 1866 and 1867 Huggins observed the spectra of two small comets, and found them to consist of a continuous spectrum, as well as of one of bright lines. These observations show that a gas in a state of luminosity is present in the comet, and that from some portions of the comet sunlight* is also reflected.

The year 1868 brought the return of two periodic comets of greater brilliancy, the comet of Brorsen (I.) and that of Winnecke (II.).

The telescopic aspect of Brorsen's comet (I., 1868) was that of a nearly circular nebula, in which the brightness rapidly increased towards the centre, but in which the existence of a nucleus was doubtful; there was only the faint trace of a tail, or more properly merely a slight expansion of the coma on the side away from the sun.

Secchi examined this comet with a simple direct-vision spectroscope, and compared the spectrum with that of Venus, bringing the planet and the comet alternately into the same place in the instrument.

Huggins observed the same comet from the 2nd to the 13th of May, and found, with Secchi, that the spectrum (Fig. 276, No. 5) was discontinuous, consisting of three bright bands; the length of the spectrum showed that the light was not

* [This is only the case if the continuous spectrum be traversed by Fraunhofer lines.]

exclusively that of the nucleus, but included that of the coma. The brightest band was in the green, about half-way between the Fraunhofer lines *b* and F. When the sky was very favourable, this band seemed reduced to a single bright line. The second band, less intense, but still very bright, was situated in the yellow-green, nearly in the middle of the space between the Fraunhofer lines *b* and D. The third band was in the blue, towards the violet, about a third of the distance between F and G. Occasionally another band could be traced in the red, but it was difficult to fix its place.

An extremely faint light, not shown in the drawing, indicated the presence of a very faint continuous spectrum.

By narrowing the slit, these luminous bands could not be resolved into lines, which is the case with the bright bands of nebulæ; it only produced a weakening of the bands of light until they completely disappeared.

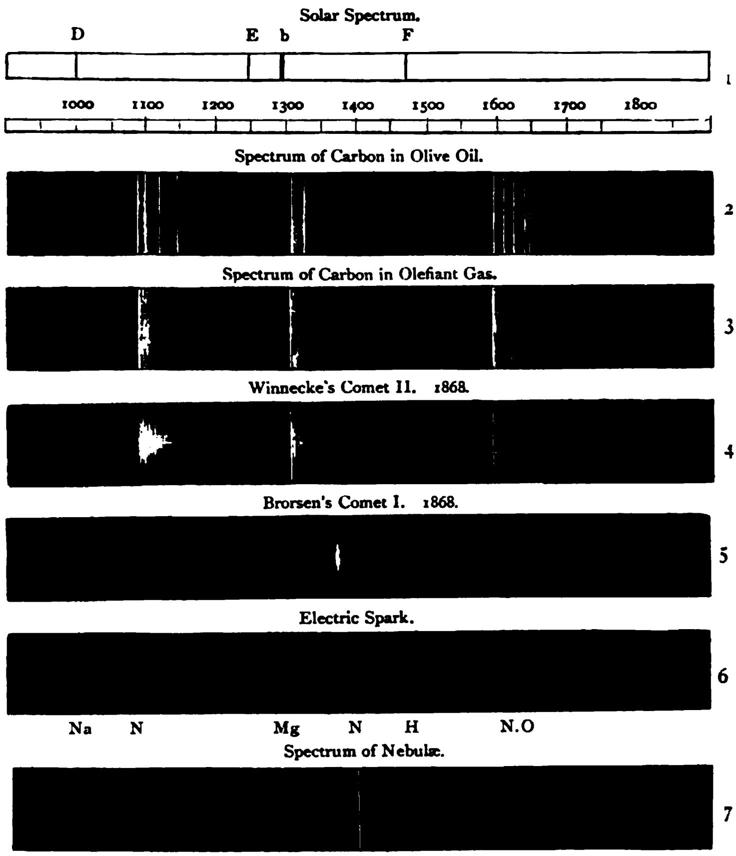
The spectrum of Brorsen's comet bears a great resemblance to that observed by Donati; but it differs essentially from the spectrum of a nebula, not only in its character, but also in the position of the bright bands. A comparison of these two spectra (Fig. 276, No. 5 and No. 7) shows this at a glance.

Comet II., 1868, was first observed on the 13th of June, by Dr. Winnecke, in Carlsruhe, and soon attained sufficient brightness to be seen by the naked eye as a star of the seventh or eighth magnitude. The diameter of the nucleus, including the extremely faint luminous envelope, amounted to about 6′ 20″, the length of the tail being more than 1°. The tail went straight out from the coma, and seemed to have no connection with the bright nucleus. The following side, that turned away from the direction of motion, was sharply defined, while the other side gradually lost itself in space.

When Secchi examined the comet on the 21st of June

with a simple spectroscope without a slit, the spectrum was seen to consist of three brilliant bands, the brightest of which was in the green, another less bright in the yellow, and the

FIG. 276.



Spectra of Brorsen's and Winnecke's Comets compared with the Spectra of the Sun, Carbon, and the Nebulæ

faintest in the blue. With one of Hofmann's direct-vision spectroscopes the three bands were well defined, and the dispersed light had disappeared. On comparing the position

of these lines with those of the spectra of various metals, it was found that the middle one lay very near to the magnesium line *b*, but the spectrum was not in full agreement with that of any metal. A great resemblance was noticed, however, to that of hydrocarbon, which led to the conclusion that the light from the self-luminous part of the comet was produced by that substance.

Huggins investigated Winnecke's comet with a spectroscope consisting of two prisms of 60°, and has given a drawing of the spectrum, together with the spectra of the substances with which it was compared. In Fig. 276, No. 4 is the spectrum of the comet, No. 2 that of the electric spark in olive oil, No. 3 the electric spark in olefiant gas; No. 6 gives the principal lines of some of the substances brought into comparison by means of the electric spark (N. = nitrogen, O. = oxygen, H. = hydrogen, Mg. = magnesium, Na. = sodium).

The apparatus employed by Huggins for these comparisons is shown in Fig. 277. The olefiant gas was contained in the glass bottle *a*, from whence it flowed through the tube *b*, into which were soldered two platinum wires *e* and *f*. At the place where the spark was to pass a hole was bored through the glass tube, the edges of the opening carefully ground, and the opening closed by a smooth plate of glass. The light of the glowing gas was thrown by the small mirror *c* on to the prism in the interior of the tube, by which it was reflected on to the lower half of the slit, while the light of the comet was received upon the upper half. The spark spectrum of the olefiant gas was thus brought into juxtaposition with the spectrum of the comet, so as to admit of an exact comparison.

Secchi's observations have been confirmed by those of Huggins; the spectrum of the comet consisted of three broad bright bands, sharply defined towards the red, but fading

away on the opposite side; Huggins did not succeed in resolving the bands into sharp lines, but the middle and brightest band appeared to commence with a well-defined bright line. When the slit was placed on the edge of the coma the three bands were still distinguishable, but when the slit was directed to the fainter light of the tail the spectrum appeared to be continuous.

FIG. 277

Huggins' Apparatus for observing the Spectra of Hydrocarbons.

If the spectrum of the comet be compared with that of carbon disengaged from olive oil or olefiant gas by the heat of the electric spark, the resemblance disappears.* The lines of hydrogen, moreover, belonging to the spectrum of

* [This statement is not correct. Huggins found, as may be seen in Fig. 276, the spectrum of this comet to be apparently *identical* with that of carbon as obtained by the passage of the induction spark in olefiant gas, not only in the position in the spectrum of the bands, but also in their general characters and relative brightness.

olefiant gas are not visible in the spectrum of the comet, so that there appears ground to consider this spectrum of bright bands to be that of carbon, and not that of any stable hydrocarbon, for Huggins found the same bands, together with the lines of nitrogen, when the spark was taken in cyanogen, and a spectrum essentially the same, but less complete, when compounds of carbon with oxygen were employed.

The same comet was spectroscopically observed by H. M. C. Wolf at Paris. It was remarked also by him that the three bright bands separated from each other by perfectly dark spaces could not be condensed into lines by narrowing the slit, and thus the spectrum offered no analogy to that of a nebula.

The spectrum of comet I., 1870 (Winnecke), was examined by Wolf and Rayet; it consisted, like the spectra of earlier comets, of three bright bands which spread out upon a continuous spectrum. Huggins found the wave-length of the brightest portion of the central band to be about 510 millionths of a millimetre, that of the second band to be 545 millionths of a millimetre, while the position of the third band could not be ascertained on account of its faintness.

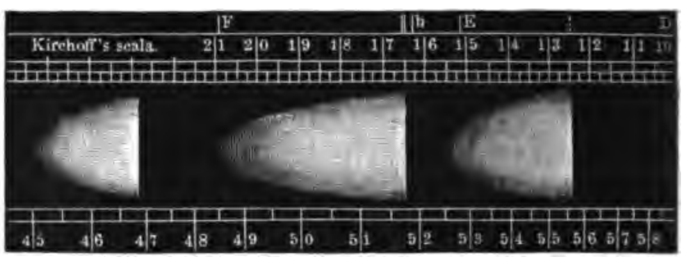
In December 1871, Young observed the spectrum of Encke's comet, and found it to consist, as shown in Fig. 278, of three bright bands, of which the central one was the most prominent. On the least refrangible side the bands were somewhat sharply defined, while on the other they were diffused. Of a continuous spectrum there was no trace, and the spectrum was the same from every part of the comet.

The spectrum of Brorsen's comet, as shown in the diagram No. 5, does not agree with that of carbon. The spectrum of carbon as obtained when the spark passes in olive oil, No. 2, differs from No. 3 only in that the bands are resolvable into fine lines. The component of olefiant gas, hydrogen, is omitted in the diagram.]

The wave-lengths for the sharply-defined edges of the three bands as determined by Young from the mean of measures extending over four days are in millionths of a millimetre as follows: 557·5, 517·4, 470·2. On the first of December, at 5h. 45m. Washington mean time, the comet passed almost centrally over a star of the ninth magnitude, so that in the nine-inch refractor with a power of 200 the star was seen as the nucleus of the comet. In the spectroscope its presence was indicated by the sudden appearance of a narrow longitudinal spectrum in the centre of that of the comet.

Comet V., 1873, was examined by Vogel on the 3rd, 6th,

FIG. 278.



Spectrum of Encke's Comet, 1871.

and 11th of September. The spectrum consisted of three bright bands sharply defined towards the red. A comparison with the spectrum of carbon showed a remarkable coincidence between the two. The wave-lengths for the edge of the bands towards the red were 563·7, 517·5, and 472·7.

The first comet of any brightness that appeared after the discovery of spectrum analysis was that discovered by Coggia on the 17th of April, 1874. It was carefully examined by Huggins during the first half of July. As soon as the slit extended over the nucleus on to the coma there appeared a spectrum of three bright bands in addition to the continuous spectrum, apparently due to the light of the

nucleus. There seemed also to be a second continuous spectrum accompanying the gas spectrum of the coma. Huggins could not decide whether in the continuous spectrum of the nucleus any dark lines were present, but D'Arrest was convinced of the existence of absorption bands, and noticed that the spectrum was shorter and fainter than that of a star of similar brightness. He remarked also upon the extreme faintness of the third band, wave-length 470.

This comet was carefully examined by Vogel. The position in wave-lengths of the three bands as determined by their sharp edges is as follows:—

	I.	II.	III.
Millionths of a Millimetre .	562·5	515·1	471·6

Estimations for the wave-lengths of the point of maximum brightness in the bands and of the diffused edge towards the violet were as follows:—

	I.	II.	III.
Brightest spot	553·8	511·8	468·9
Edge	541	500	465

Upon the reappearance of Brorsen's comet in 1879, it was spectroscopically observed by Konkoly. The spectrum showed the usual three bright bands and a continuous spectrum extending from 573·2 to 455 millionths of a millimetre wave-length, which could not have been due solely to the nucleus, but must have belonged to the whole nebulous mass, as the breadth was equal to that of the bands.

In the spectrum of comet IV., 1880, Konkoly observed four bands, of which the fourth was very faint. Wave-length in millionths of a millimetre, 561·0, 549·2, 516·3, and 485·6.

From the observations hitherto made, it appears that the typical spectrum of a comet consists of three bands with edges, sharply defined towards the red, and diffused towards the violet. The brightest portion of each band is not, however, of the same wave-length in each comet. The resem-

blance between the spectrum of a comet and that of the hydrocarbons is so great that it is scarcely possible to escape the conclusion that in the denser parts of the comet compounds of carbon with hydrogen must be present in a state of incandescence. In view of the tremendous convulsions which occur in the constitution of a comet, as revealed by telescopic observation, in which the motion of vaporous masses is on a scale commensurable only with the eruptions which take place on the sun's surface, the idea naturally suggested is that of a simultaneous development of prodigious heat.

With regard to the constitution of a comet when at a distance from the sun Olbers considers that the particles of which a comet is composed must be so near the point of volatilizing, that a slight increase of temperature would cause volatilization to set in, or give rise to some other repulsive force.

As the result of close reasoning upon the stability of cosmical matter, Zöllner arrived at the conclusion, that a detached mass of vapour or gas floating in space could not assume a condition of equilibrium, but by a gradual process of attenuation must eventually lose itself in space. Hence Zöllner assumes that the *cosmical* substance of a comet is liquid.

In explanation of the outflow of the nucleus towards the sun, and the consequent formation of a tail in the opposite direction, it had been assumed by Olbers that the vapour developed from the comet and its atmosphere was *expelled* not only by the comet, but also by the sun.

Bessel has expressed almost similar views upon the formation of the tail, and concurs with Olbers in rejecting the hypothesis of Newton that tails of comets are formed by the lighter particles ascending through the denser medium of ether in the same manner as smoke, or a balloon, ascends

from the earth in our atmosphere. The formation of the stream of vapour and of the tail he attributes to a ***polar force*** comparable to the action of electricity or magnetism, but without stating what is to be understood by polar force. The phenomenon of the tail's formation is explained by Bessel on the assumption that the repulsive action of this polar force of the sun decreases in different parts of the comet's orbit in proportion to the square of the distance, and that the particles of the tail, after they have travelled beyond the sphere of attraction of the comet, may be regarded as free particles of matter upon which the sun's influence is alone felt.

The observations of Pape and Winnecke upon the bright comets of 1858 and 1862 were similar to those of Olbers and Bessel as to the outflow of streams from the nucleus and their variation in direction. In the comet of 1862, this motion was also seen to assume an oscillatory character, which has been explained by Winnecke as follows:—"The ***reaction*** of the issuing stream, the direction of which rarely passes through the centre of the nucleus, gives to the nucleus a rotatory motion which ceases and assumes another direction as soon as a second stream from another point overcomes the expiring efforts of the first."

In Bessel's elaborate treatise upon Halley's comet, the curve in the tail is regarded as the united effect of the comet's motion and the repulsive power of the sun upon the attenuated particles issuing from the nucleus. Professor Bredichin, of Moscow, in developing this theory, assumes further that the amount of curvature depends upon the specific gravity of the substance composing the tail, and has arrived at the conclusion that comets may be divided into three classes. In the first type hydrogen forms the chief constituent, in the second the hydrocarbons, and in the third iron, chlorine, etc.

The kind of repulsive force exerted by the sun upon the material of the comet has not yet been discovered. Zöllner regards it as identical with electricity.

The connection of comets with meteor-swarms will form the subject of a future page.

91. The Comet Wells, 1882.

From the position and appearance of the bright bands forming the spectra of comets, there is little doubt that in the comets hitherto examined carbon, hydrogen, nitrogen, and apparently also oxygen are present in a state of incandescence. The comets thus examined numbered about twenty, which seemed to afford good ground for concluding that all future comets would present a spectrum of similar type. The recent investigation of the Wells comet, discovered in 1882, revealed the remarkable fact that its spectrum was of an entirely different order.

During the month of May, 1882, the spectrum of this comet was examined by several observers, and found to consist of the well-known three bright bands, although considerably fainter than was to be expected from the brightness of the comet. On the 31st of May it was noticed, both at Potsdam by Professor Vogel and at Greenwich by the Astronomer Royal, Mr. Christie, that upon the continuous background of the spectrum an intense bright yellow line was visible, which was at once recognized as coincident with the double line of sodium. On the 5th of June the two sodium lines appeared of very different intensity; the most refrangible was very much brighter, and about five times broader, than the other, and diffused at the edges. This would lead to the supposition that the density of the incandescent sodium vapour was very great.*

* [This reasoning is by no means obvious. Laboratory experiments on sodium vapour do not confirm this supposition.]

mparing the lines of the comet with those of sodium repeatedly received the impression that the centre of broad line in the comet's spectrum was not exactly coincident with the corresponding line D_2 of the flame, but was displaced somewhat towards the red. If this were so, the slight displacement could only be explained by the motion of the source of light away from the observer, and, in reality, at the time of the observation the comet was moving in a direct line away from the earth at a speed of more than 30 miles per second, corresponding to a displacement amounting to $\frac{1}{15}$ of the separation of the D-line, an amount quite perceptible with the dispersive power employed.

The sodium lines were visible not only in the nucleus, but were very intense in other parts of the comet. The light of the incandescent sodium vapour overpowered so completely all other rays of the comet's own light, as well as all reflected light, that the comet, when viewed without a spectroscope, appeared of a yellow colour, and, when observed by Vogel with a wide slit, the whole form of the comet was seen with the yellow light of the wave-length D in a manner similar to the observation of the solar prominences.

An unfavourable change in the weather prevented any further observations.

At Greenwich the spectrum of the comet was first observed on April 24th. There were then faintly visible places of maximum intensity in the green and the blue-green. On the 13th of May a brighter band near the E-line was suspected. On the 20th of May the spectrum presented the same appearance except for the indication of three dark bands, of which the central one had a wave-length of 5500 ten-millionths of a millimetre, and the third was situated near D, towards the blue. The spectrum of the nucleus extended from wave-length 4300 to 6150 ten-millionths of a millimetre. The tail showed a faint continuous spectrum,

visible only in the green. On the 31st of May, two dark bands appeared in the spectrum of the nucleus near F, the least refrangible of which was found to have a wave-length of 4862 ten-millionths of a millimetre. There was also a bright stripe in the red of which the wave-length was approximately determined to be 5146 ten-millionths of a millimetre; a second bright stripe had apparently a wave-length of 5328, and finally there was a dark band near D towards the blue. On the same evening, the yellow line in the spectrum of the comet's head was first noticed by Christie, which on June 8th was found to have gained considerably in intensity. As a result of the intense nature of this yellow light, the nucleus of the comet appeared in the telescope of an orange colour. The yellow line, when compared with the D-line, appeared somewhat displaced towards the red, but the amount of displacement could only be estimated, and represented a movement of the comet away from the earth at a speed of 79 miles per second.

The coincidence of the bright lines with D observed by Vogel was confirmed by Professor Bredichin of Moscow, by whom the image of the nucleus was also seen by the yellow light admitted through a widened slit.

The yellow line was observed on the 3rd of June by Dunér, at Lund, and the wave-length determined by direct measures to be 589·45 millionths of a millimetre. The bright line was to be seen in the tail to a distance of 1′ from the nucleus. On the 5th of June Dunér again saw the bright line, and found that its intensity had increased. The wave-length as measured on this occasion was 589·0 millionths of a millimetre, or the mean of all the measures 598·2, which coincides with the wave-length given by Ångström for the central point between the two D-lines.

At Pulkova the comet was spectroscopically observed by Hasselberg, on June 4th, 5th, and 7th. The bright yellow

line was seen, and its coincidence with the sodium line established, but of the usual three bands not a trace remained. As they had been seen by Bredichin, Konkoly, and Vogel, during the latter half of May, a complete change in the spectrum of the comet must have taken place since the end of that month. The appearance of the bright sodium line might easily be explained by the increase of temperature to which the comet would be exposed on its approach to the sun; perihelion was reached on the 10th of June, but this would not explain the disappearance of the three bands. If, for instance, sodium be burnt in a flame of hydrocarbon, the spectrum of the hydrocarbon is not the least affected by the addition of the bright sodium line; but if the spark be employed, a very different phenomenon presents itself. If sodium steeped in naphtha be placed in a Geissler tube, and, after the air has been exhausted, a powerful electric current from a Ruhmkorff induction coil in connection with a Leyden jar be passed through, an intense spectrum of the vapour of hydrocarbon will be formed. If the tube be heated till the sodium be vaporized, the hydrocarbon spectrum is at first intensified, but, as soon as all the sodium is vaporized, the spectrum of the hydrocarbon will almost disappear, while the yellow sodium line is extremely brilliant. If by a decrease of temperature the sodium vapour becomes condensed, its spectrum gradually fades, while that of the hydrocarbon again becomes brilliant. Hence it appears that in a mixture of the vapours of sodium and naphtha the sodium alone conducts the electric current. If it be assumed therefore that the light of the comet is chiefly caused by electric discharges within its substance, the analogy it presents to the phenomena of the spectra of mixed vapours is very striking. This has led Hasselberg to the conclusion that in the comet Wells the sodium became vaporized under the action of the solar heat, and that the observed phenomena were

chiefly caused by electrical discharges in the body of the comet.

It has been shown both by Alexander Herschel and Konkoly that variations occur in the spectra of the periodic meteor-swarms; it is not, therefore, surprising if under the action of solar heat chemical constituents should be found in the nucleus of a comet wholly different from any before observed.

92. Photographs of the Spectra of Comets.

In the observations of the spectra of comets hitherto con-

Fig. 279.

Huggins' Photograph of the Spectrum of Comet II. 1881.

sidered, the examination has been restricted to the visible spectra. Huggins was the first who had the good fortune to obtain a photograph of the spectrum of a comet, that of comet II., 1881, which he accomplished by means of the apparatus described in § 85. A drawing from the photograph is given in Fig. 279. It shows a continuous spectrum extending from about G to K, in which various Fraunhofer lines are visible, among others G, *h*, H, and K. The visibility of these lines is important as evidence that the continuous spectrum is due to reflected sunlight.

A second spectrum is also present consisting principally of two groups of bright lines. These evidently arise from the three bands of which the visible spectrum is usually com-

posed. Careful measures of the position of the bright lines in the ultra-violet portion of the spectrum led Huggins to suggest that they coincided with the lines shown by Liveing and Dewar to be found in the spectrum of cyanogen. A few days later the same spectrum was photographed by Draper. The bright lines were visible, but there was no indication of the Fraunhofer lines.

With the same apparatus Huggins succeeded on the 31st of May in photographing the spectrum of comet Wells, the exposure being an hour and a quarter. For the sake of comparison the spectrum of *α* Ursæ majoris was photographed on the same plate. The spectrum of the comet Fig. 280 was continuous and bright from F to a little beyond H. No

Fig. 280.

Photographed Spectrum of the Comet Wells, by Huggins.

Fraunhofer lines were visible. The slit of the spectroscope was somewhat wider than when photographing the spectrum of the comet of 1881. This would tend to diminish the sharpness of the lines, but in the spectrum of *α* Ursæ majoris, photographed under similar circumstances, the lines G and H are clearly to be distinguished. From this Huggins concludes that the portion of the light peculiar to the comet by which a continuous spectrum is formed is much greater in proportion to the reflected solar light than in the comet of 1881.

The photograph of the spectrum, as was to be expected, exhibited in the most refrangible part a type wholly at variance with any before observed. The prominent group of lines in the ultra-violet due to cyanogen were not visible in

the photograph, nor were the bright groups of lines between G and *h* and between *h* and H. The head of the comet seen through the slit appeared sharply defined, as was also the continuous spectrum formed by the nucleus, which in this comet was very marked. In the continuous spectrum there were at least five places of maximum brightness, which Huggins considered were most probably due to groups of lines not defined in the photograph, as in the photograph the bright places projected on one side beyond the continuous spectrum.* This side corresponds with the light that came from the portion of the nucleus turned towards the sun. The photographic image was too faint to measure exactly the commencement and termination of the groups. The wave-lengths of the brightest portions in ten-millionths of a millimetre were as follows: 4253, 4412, 4507, 4634, 4769.

93. Falling Stars, Meteor Showers, Balls of Fire and their Spectra.

No one can observe the heavens on a clear night with some amount of attention and patience without noticing the phenomenon of a falling star, or meteor which suddenly appears in the heavens, and shooting across the sky, vanishes after a few seconds. As a rule, meteors can only be seen of an evening, or at night; but in some instances their brilliancy has been so great as to render them visible in the daytime.

It sometimes happens that the number of meteors is so great that they pass over the heavens for hours together like flakes of snow. Before sunrise on the morning of the 12th of November, 1799, Humboldt and Bonpland, when on the

[* In a photograph of a continuous spectrum, on which bright lines are superposed, it frequently happens that on the negative the bright lines project beyond the continuous spectrum. According to common optics this should not be the case, but it can be accounted for on other grounds.]

coast of Mexico, witnessed during the space of four hours the fall of thousands of meteors, most of which left a track behind them of from 5° to 10° in length; some exploded, and others, with a nucleus as bright as Jupiter, emitted sparks.

On the 12th of November, 1833, there fell a similar shower, in which, according to Arago's estimation, two hundred and forty thousand passed over the heavens in three hours. The phenomenon again occurred in 1866, and was watched by many observers. Occasionally these fiery substances fall upon the surface of the earth; they are then termed meteoric stones, aerolites, or meteoric iron. They are also designated chance meteors or meteoric showers, according as to whether they traverse the heavens singly in various directions or appear in great numbers following a common path, thus indicating that they are parts of a great whole.

It has been ascertained through the researches of Schiaparelli, Le Verrier, Weiss, and others, that these meteors are fragmentary masses, revolving round the sun in orbits crossing that of the earth, and that, when drawn by its attraction into our atmosphere, they are set on fire by the heat generated through the resistance offered by the compressed air.

The chemical analysis of those meteors which have fallen to the earth proves that they are composed of terrestrial elements. Their chief constituent is metallic iron, mixed with various silicious compounds; in combination with iron, nickel is always present; among the silicates, olivine and augite are of most frequent occurrence. In the meteoric stones hitherto examined, the following substances have been found, oxygen, hydrogen, sulphur, phosphorus, carbon, aluminium, magnesium, calcium, sodium, potassium, manganese, titanium, lead, lithium, and strontium.

Aerolites may be divided, as Gastav Rose suggests, into two classes, iron and stone. The first are distinguished

chiefly by the presence of nickel; the latter contain principally hydrogen, silicic acid, silicate, clay, and lime.

Of late it has been discovered that in many, and probably in all, meteors certain gases are enclosed, especially hydrogen and carbonic acid gas, which may be disengaged by the process of heating in an air-tight vessel. Graham, who was one of the first in this field of research, showed that in the iron of the Lenarto meteorite which fell at an unknown date, the hydrogen contained equalled nearly a third of the volume. The gases of meteors have since been studied by Wright, by whom specimens of both kinds, five of iron and five of stone, were subjected to chemical analysis. The following results were obtained: the figures in the first series give the volume of gas in each meteor at a temperature of 500° C.; the figures in the second series refer to a temperature of red heat.

(*a*) METEORIC IRON.

Meteorite of	Volume of enclosed gas.	Constituents of the Gas. CO_2	CO	H	CH_4
Tazewell ...	1·87	18·34	38·45	41·51	——
	1·30	7·76	45·75	44·76	——
Singlespring ...	0·65	19·98	13·52	60·92	——
	0·32	1·10	10·39	84·40	——
Arva	8·89	18·20	38·72	40·62	——
	38·24	11·25	74·59	12·84	——
Texas	1·10	9·76	8·43	81·81	——
	0·19	2·18	48·58	49·24	——
Dickson ...	2·2	13·30	15·30	71·40	——

(*b*) METEORIC STONE.

Ohio	2·06	82·28	2·16	12·37	2·26
	0·93	16·79	8·71	69·43	1·66
Pultusk ...	0·99	81·01	1·99	13·36	1·73
	0·76	33·97	7·35	49·99	6·00
Parnallee ...	1·56	87·53	1·13	8·72	1·22
	1·17	72·43	2·53	20·03	3·22
Weston ...	2·69	86·29	1·84	8·59	1·19
	0·80	62·18	3·43	28·16	3·10
Iowa	1·04	58·04	4·01	34·82	0·00
	1·46	19·16	0·21	74·49	0·00

The two tables exhibit a striking contrast in the composition of the iron and stone meteorites; the latter at a lower temperature yield a much larger volume of gas, and the composition of the gas also widely differs. In the meteoric iron at a temperature of 500° C. the carbonic acid gas never amounts to 20 per cent. of the entire volume, while with one exception the carbonic oxide is proportionally considerably greater. In the meteoric stone, on the contrary, the proportion per cent. of the carbonic oxide is very small, while at a temperature of red heat the carbonic acid gas exceeds half the volume of all the gas present. The extreme preponderance of carbonic acid gas may be regarded, according to Wright, as the chief characteristic of the stone meteorites, and it is further remarkable that the spectra from these meteoric gases are very similar to the comet spectra of three bright bands.

Dr. Flight has recently made the analysis of the gases contained in a meteoric stone immediately after its fall, and obtained the following results:

Carbonic acid gas	0·12
Carbonic oxide	31·88
Hydrogen	45·79
Carburetted hydrogen	4·55
Nitrogen	17·66
	100·00

The opinion seems unanimous that the gases found within the meteors could not have been introduced from our atmosphere during the short period of their fall; moreover, the chief constituent of the gas is hydrogen, of which but a small amount exists in the atmosphere. From this it appears that the nucleus of a comet (p. 498) is composed of the same gases as have been found enclosed in aerolites, namely carbon, hydrogen, nitrogen, oxygen, and their compounds.

The height at which meteors appear is very various, and

ranges chiefly between the limits of 46 and 92 miles; the mean may be taken at 66 miles. The speed at which they travel is also various, generally about half as fast again as that of the earth's motion round the sun, or about 26 miles in a second; the maximum and minimum differ greatly from this amount.

When a dark meteorite of this kind, having a velocity of 1,660 miles per minute, encounters the earth, flying through space at a mean rate of 1,140 miles per minute, and when through the earth's attraction its velocity is further increased 230 miles per minute, this body meets with such a degree of resistance, even in the highest and most rarefied state of our atmosphere, that it is impeded in its course, and loses in a very short time a considerable part of its momentum. By this encounter there follows a result common to all bodies in motion which suddenly experience a check; the motion is converted into heat. When a cannon-ball strikes suddenly with great velocity a plate of iron, a spark is seen to flash from the ball; under similar circumstances a lead bullet becomes partially melted. The heat of a body consists in the vibratory motion of its smallest particles; an increase of this molecular motion is synonymous with a higher temperature, a lessening of this vibration with a decrease of heat. Now, if a body in motion, as, for instance, a cannon-ball, strike against an iron plate, or a meteorite against the earth's atmosphere, in proportion as the motion of the body diminishes and the external action of the moving mass becomes annihilated by the pressure of the opposing medium upon the foremost molecules, the vibration of these particles increases; this motion is immediately communicated to the rest of the mass, and by the acceleration* of this vibration through all the particles the temperature of the body is raised. This phenomenon is described by the expression *the conversion*

[* Increase in amplitude of these vibrations.]

of the motion of the mass into molecular action or heat; it is a law without exception that where the *external* motion of the mass is diminished, an internal motion among its particles or heat is set up. It may be supposed that even in the highest and most rarefied strata of the earth's atmosphere, the velocity of the meteorite would be rapidly diminished by its opposing action. This being so shortly after entering our atmosphere, the vibrations of the molecules would become increased to such a degree as to raise them to a white heat. They would then either become partially fused, or if the meteorite were sufficiently small, would be dissipated into vapour, and form a luminous track.

Haidinger, in a theory embracing all the phenomena of meteorites, explains the formation of a ball of fire round the meteor by supposing that the meteorite, in consequence of its rapid motion through the atmosphere, presses the air before it till it becomes luminous. The compressed air in which the solid particles of the surface of the meteorite glow then rushes on all sides, but especially over the surface of the meteor behind it, where it encloses a pear-shaped vacuum which has been left by the meteorite, and so appears to the observer as a ball of fire. If several such bodies enter the earth's atmosphere simultaneously, the largest precedes the others, because the air offers least resistance to its proportionately smallest surface; the rest follow in the track of the first meteor, which is the only one surrounded by a ball of fire. When by the resistance of the air the motion of the meteor is arrested, it remains quiescent for a moment; the ball of fire is extinguished; the air rushes into the vacuum behind the meteor, which being left to the action of gravitation, falls to the earth. The loud detonating noise usually accompanying this phenomenon finds an explanation in the violent concussion of the air behind the meteor.

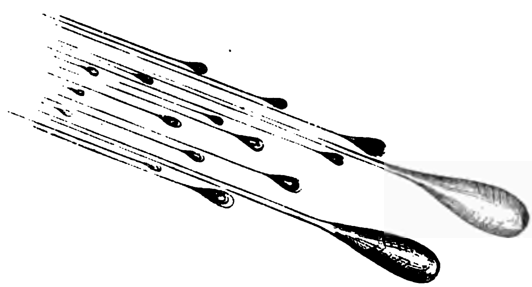
The extinction of most meteors before reaching the earth

seems to show that their mass is small. If the distance of a meteor be ascertained, as well as its apparent brightness, it is possible, by comparing its luminosity with that of a known quantity of ignited gas, to estimate the degree of heat evolved in the meteor's combustion. As this heat is due to the motion of the meteor being impeded by the resistance of the air, and as this motion or momentum depends alone upon the speed of the meteor and upon its mass, it is possible when the rate of motion has been ascertained to determine the mass. Prof. Alexander Herschel has calculated that the meteors of the 9th and 10th of August, 1863, which equalled the brilliancy of Jupiter or Venus, possessed a mass of from five to eight pounds, while those which were only as bright as stars of the second or third magnitude were not more than about ninety grains in weight. As the majority of meteors do not equal stars of the second magnitude, faint meteors must weigh only a few grains, for, according to Prof. Herschel's computation, the five meteors observed on the 12th of November, 1865, some of which surpassed in brilliancy stars of the first magnitude, did not average in weight more than five grains; and Schiaparelli from other phenomena estimated the weight of a meteor to be about fifteen grains. The mass, however, of the meteoric stones which fall to the earth is considerably greater, whether consisting of one single piece, such as the celebrated iron-stone discovered by Pallas in Siberia, which weighed about 2,000lb., or of a group of small bodies penetrating the earth's atmosphere in parallel paths, as shown in Fig. 281, and which, from a simultaneous ignition and descent upon the earth, present the appearance of a large meteor bursting into several smaller pieces. Such a shower of stones, accompanied by a bright light and loud explosion, occurred at L'Aigle, in Normandy, on the 26th of April, 1803, when the number of stones found in a space of 14 square miles exceeded

2,000. In the meteoric shower that fell at Knyahinya, in Hungary, on the 9th of June, 1866, the principal stone weighed about 800 lb., and was accompanied by about a thousand smaller stones, strewed over an area of 9 miles in length by 3½ broad.

The most striking example of such a cosmical cloud of small bodies, existing with scarcely any connection one with another, is exhibited in the meteoric showers occurring periodically in August and November. On certain nights in the year the number of meteors is extraordinarily great, and at these times they radiate from certain fixed points in the heavens.

FIG. 281.



Balls of Fire seen through the Telescope.

The meteor shower which every year occurs on the night of the 10th of August, and proceeds from the constellation of Perseus, is mentioned in many old writings. The shower of the 12th and 13th of November occurs periodically every thirty-three years, and for three years in succession, with diminishing numbers; it was this shower that Alexander von Humboldt and Bonpland observed at Cumana, on the 12th of November, 1799. On its recurrence on the 12th of November, 1833, it was compared by Arago to a fall of snow, and was observed again in its customary splendour in 1866 and 1867. Besides these two principal showers, there are many

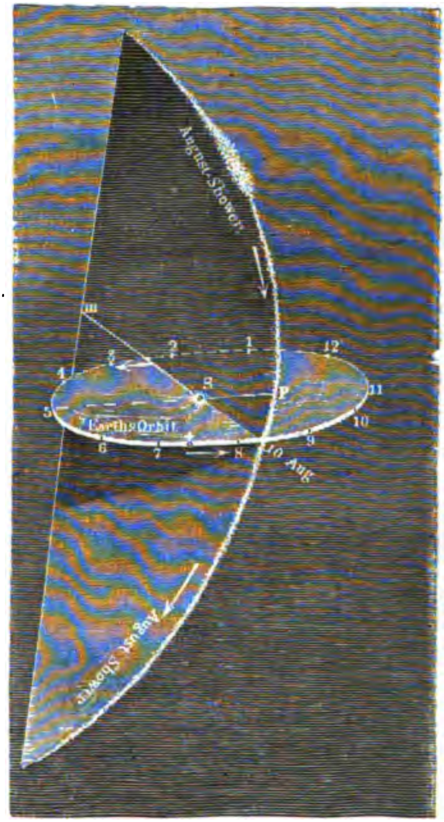
others recurring at regular intervals; each of these is a cosmical cloud composed of small dark bodies which, loosely held together like the particles of a sand cloud, circulate round the sun in one common orbit. The orbits of these meteor streams are very diverse; they do not lie approximately in one plane like those of the planets, but cross the plane of the earth's orbit at widely different angles. The motion of the individual meteors is in the same direction in one and the same orbit; but while this direction is in some orbits in conformity with that of the earth and planets, in others it is retrograde.

The earth in its revolution round the sun occupies each day a different place in the universe; if, therefore, a meteoric shower passes through our atmosphere at regular intervals, there must be at the place where the earth is at that time an accumulation of these small cosmical bodies. A cosmical cloud, however, cannot remain at a fixed spot in our solar system, but must circulate round the sun as do the planets and comets. It therefore follows that the path of a periodic shower must intersect the earth's orbit, and when the meteors are visible to us, the earth must either be passing through the cloud, or else very near to it.

As we have said, the meteor shower of the 10th of August, the radiant point of which is situated in the constellation of Perseus, takes place nearly every year, with varying splendour; we may, therefore, conclude that the meteors composing this group form a ring round the sun, and that the earth every 10th of August is at the spot where this ring intersects our orbit. It also follows that the ring of meteors is not equally dense in all parts, but that in some places these small bodies must be more or less thinly scattered. Fig. 282 shows a small part of the elliptic orbit described by these meteors round the sun S. The earth encounters this orbit on the 10th of August, and

goes straight through the ring of meteors. The dots along the ring indicate the small dark meteors which ignite in our atmosphere, and are visible as shooting stars. The line *m* is the line of intersection of the earth's orbit and that of the meteors; the line P S shows the direction of the major axis of their orbit. This axis is fifty times greater than the mean diameter of the earth's orbit; the orbit of the meteors is inclined to that of the earth at an angle of 64° 3′, and their motion is retrograde, or contrary to that of the earth.

Fig. 282.

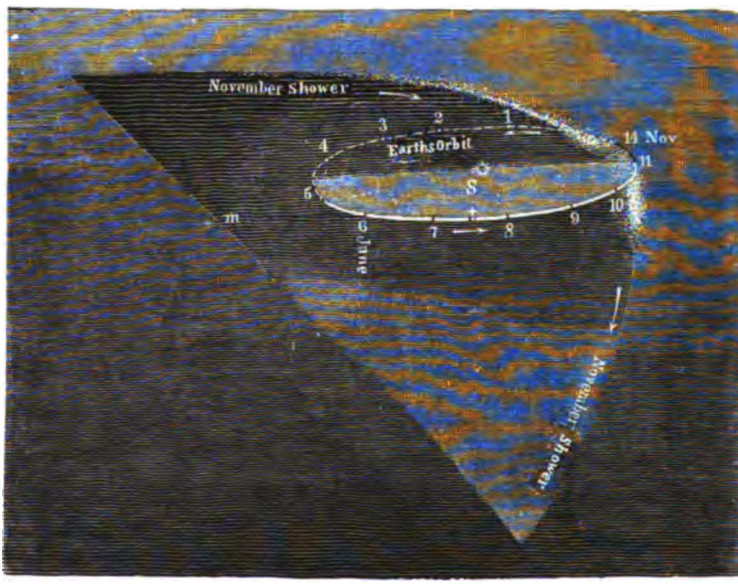


Orbit of the Meteor Shower of the 10th August.

The shower which has been observed on the 12th or 13th of November, and which occurs every thirty-three years, proceeds from a point in the constellation of Leo. The meteors composing this shower, unlike those in August, are not distributed along the whole course of their orbit, so as to form a ring entirely filled with meteoric particles, but constitute a dense cloud, of an elongated form, which completes its revolution round the sun in thirty-three years, and crosses

the earth's path at that point where the earth is every 13th of November. As the November shower is repeated during three successive years on the 13th of that month, but with diminished splendour for the last two years, the meteors must extend so far along the orbit as to require three years before they have all crossed the earth's path at the place of

FIG. 283.



Orbit of the November Meteor Shower.

intersection; they are, besides, unequally distributed, the preceding part being much the most dense.

A very small part of the elliptic orbit, and the distribution of the meteors during the November shower, is represented in Fig. 283. As shown in the drawing, this orbit intersects that of the earth at the place where the earth is about the 14th of November, and the motion of the meteors, which occupy only a small part of their orbit, and are very unequally

distributed, is retrograde, or contrary to that of the earth. The inclination of this orbit to that of the earth is only $17^\circ\ 44'$; its major axis is about ten and one-third times greater than the diameter of the earth's orbit, and the period of revolution for the densest part of the meteorites round the sun S is thirty-three years three months.

The paths of the various meteors belonging to the same swarm appear to start from the same point in the heavens, termed the *radiant point;* in the August swarm this is situated between the constellations of Perseus and Cassiopeia, in the November swarm it lies close to the star ζ in Leo. By this it is not meant that all meteors of the same swarm really proceed from the same point in the universe, but that the paths of most of them traced backwards would converge to the same point in the sky. Some few meteors cannot be traced to any certain radial point, and are therefore termed *sporadic.* The apparent convergence of such meteor paths is the effect of perspective: in reality they are nearly parallel, and they present the appearance of diverging lines on the same principle as the rays of the sun seem to diverge on issuing from an opening in a cloud. Even when the meteor-fall is not so striking, a radial point is often to be found; a great number of such periodic swarms have been discovered by Heis, Greg, and Alex. Herschel, and the radial points approximately determined.

The affinity between comets and meteors was recognized by Chladni, but Schiaparelli, of Milan, was the first to treat successfully and with wonderful acuteness the various phenomena exhibited by these mysterious heavenly bodies. He shows that an intimate connection exists between comets and meteor-swarms, inasmuch as they both describe similar orbits around the sun, and that even in some cases a comet may be in one part of the orbit and a meteor-swarm at another part of the same orbit. Between the orbit of the

August meteor ring and that of the comet of 1862, No. 3, he discovered so close an agreement that no doubt can be entertained of their identity.

A cloud of meteors can only be observed as a meteor shower when it crosses the earth's orbit at a moment when the earth is also there, so that the meteors pass through our atmosphere.

The calculations of Schiaparelli, Oppolzer, Peters, and Le Verrier have discovered in the small comet of 1866, No. I., first observed by Tempel, of Marseilles, the cause of the November shower of meteors. The orbit of this comet agrees very exactly with that of the meteor-swarms of the 14th and 15th of November. The elements are as follows :

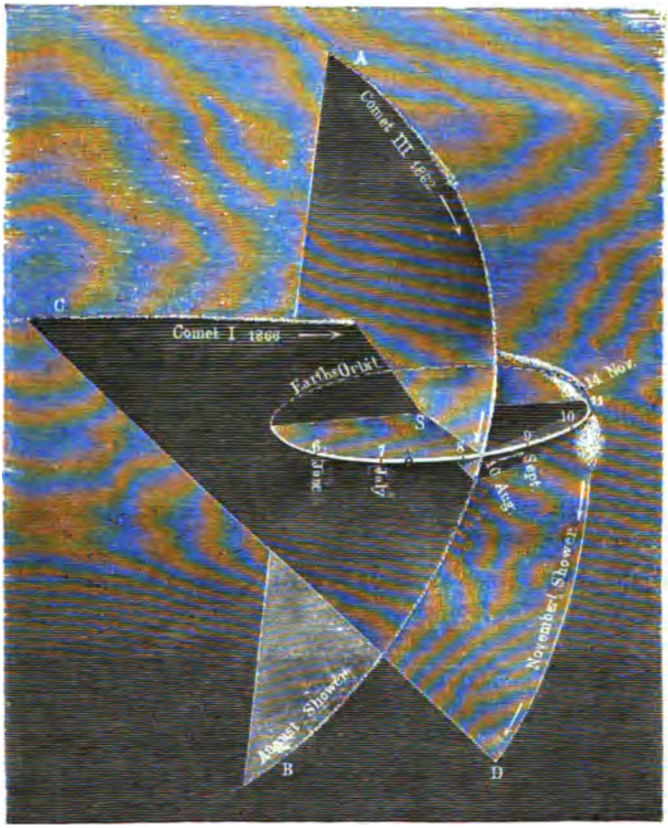
	For the Meteor-swarm.	For the Comet.
Passage of Perihelion. .	Nov. 10·092	Jan. 14·160 1866.
Length of Perihelion . .	56°25′	60°28′
Length of Node . . .	231°28′	231°26′
Inclination of the Orbit to the Ecliptic . . .	17°44′	17°18′
Perihelion distance . .	0·9873	0·9765
Eccentricity . . .	0·9046	0·9054
Half of major axis . .	10·340	10·324
Period	35·250 years	33·176 yrs.
Direction of motion . .	retrograde	retrograde

The transformation of this comet into a ring of meteors has not proceeded nearly so far as in the case of the comet 1862, No. III. ; the existence of the ring is of much more recent date, and, therefore, the distribution of the meteoric substances along the orbit has not continued long enough for the ring to be fully developed. In Fig. 284, C D represents a portion of the orbit of this comet which is identical with the orbit (Fig. 283) of the November meteors. In the yearly recurring meteor-swarm of April 20th, a similar connection is to be discovered with the comet of D'Arrest.

Our knowledge upon this subject is now no longer re-

stricted to the few cases just cited. In a list arranged by Alexander Herschel, seventy-one such examples are to be found.

FIG. 284.



Orbits of the August and November Meteor Showers. (Orbits of Comets III., 1862, and I., 1866.)

That under certain circumstances a comet may become dissolved into a swarm of meteors was proved by the great meteor fall that occurred on the night of the 27th and 28th of November, 1872, which gives great support to the theory of

Schiaparelli. On that evening there suddenly fell an enormous number of meteors, which quite overshadowed in magnitude the ordinary fall of meteors occurring on the 12th and 14th of that month. At Münster, Prof. Heis counted 2,200 meteors in fifty-three minutes, while at Göttingen the number per hour as seen by three observers was 7,710. At Berlin during the full splendour of the phenomenon counting was out of the question. At Leipsic between the hours of 7 and 8, 1,212 meteors were counted, and at Athens the total fall of meteors during that night, as estimated by Prof. Schmidt, was 30,000, an estimation which does not seem too high when it is considered that the number actually counted by Secchi and his assistants amounted to 14,000. The majority of the meteors proceeded from a point in Perseus, but many came from Andromeda. This radial point is, as before said, the effect of perspective; the paths of the individual meteors are parallel, and only appear to proceed from a point upon the same principle that the parallel rows of trees in an avenue appear to the observer at a distance to meet in a point.

If the speed of a meteor and its radial point be ascertained, its orbit round the sun may be calculated. Schiaparelli undertook this calculation for the meteor-swarm of the end of November, and discovered so close an agreement with the orbit of Biela's comet that there could be no doubt of their identity. The orbit of that comet is so situated that the point at which it crosses the plane of the earth's orbit is almost precisely at the same distance from the sun as the earth's orbit at that spot. The length of its descending node upon the plane of the ecliptic is 66°, and this spot was reached by the earth in 1872, on the night of the 27th and 28th of November. Now, as at this place the orbit of Biela's comet is only slightly less distant from the sun than the earth's orbit, the earth's course for a short time lay in close proxi-

mity to that of the comet. To use a familiar illustration, the two orbits might be likened to two lines of railway, and this spot to the place where they run almost close together, while at every other spot they run in different directions. Two trains proceeding on these two tracks would only be in proximity when simultaneously travelling along this piece of road. It is just so with the earth and Biela's comet. We know that the earth was at the spot in question on the 27th of November, but of the comet we know nothing certain. It was last seen in the autumn of 1852 (see p. 505), and according to calculation ought to have reappeared during the winter of 1865-66, but was never again seen, notwithstanding the diligent search of astronomers. This mysterious disappearance of a large heavenly body, or rather of two, for the comet had separated into two, created a great sensation at the time, and there seemed some colour for the supposition that it had become partially dissipated. This conclusion seemed to receive confirmation by the fall of meteors on the 27th and 28th of November, 1872. Had the comet, for instance, remained unchanged, the earth could not have been in its neighbourhood upon that day, inasmuch as it must long ago have passed the point in question, its perihelion occurring in the early part of October. Should the comet, however, have become dissolved into an elongated meteor-swarm, strewn along the orbit, it is quite possible that the earth in crossing this spot might encounter a portion of the swarm which might be passing at the moment. This appears to have really been the case, and the earth to have passed through a part of the swarm, or by its force of attraction to have drawn to itself a more or less considerable portion of these meteors.

While observing the surprising fall of meteors on the 27th of November, it occurred to Prof. Klinkerfues of Göttingen that it might perhaps be possible to discover the head of the comet, of which the dissolved portion was visible

as a meteor shower. This could only be sought for in the southern hemisphere; he, therefore, telegraphed to Mr. Pogson, the director of the Madras observatory, to seek for a comet near the star θ Centauri. The request was not in vain, for a comet was really found in the place indicated, and was observed by Pogson on two occasions. Two observations, however, do not suffice for the calculation of a comet's orbit, but from these it appeared that the orbit was very similar to that of Biela's comet, but whether the identity was complete remained undecided.

By the side of these important conclusions which the observation and acuteness of modern astronomers have been able to make concerning the nature and mutual connection of nebulæ, comets, meteors, and balls of fire, the results of spectrum analysis as applied to meteors will seem to be exceedingly scant. This is easy to understand when we reflect how rapidly these fiery meteors rush through our atmosphere, and how difficult it is to lay hold of them with the spectroscope during their instantaneous apparition. Before the instrument can be directed to a meteor or ball of fire, and the focus adjusted, the object has disappeared from view. The application, therefore, of spectrum analysis to these fleeting visitors is left almost entirely to chance, and is mainly confined to those nights in which a shower of meteors is expected to occur.

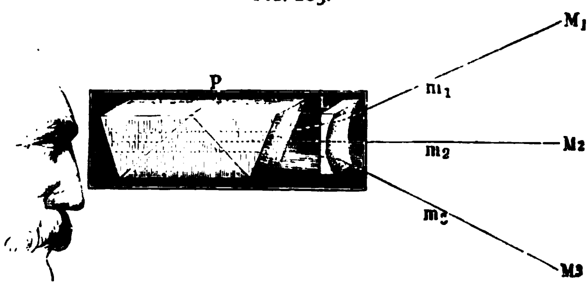
In 1865 Alexander Herschel drew attention to the expected fall of meteors in the ensuing year, and suggested that they should be observed with the spectroscope, on the ground that some few spectroscopic observations previously made had shown the spectrum of a meteor to be a continuous one, without any dark lines. Browning undertook the investigation, and from his observatory at Upper Holloway, near London, during the nights of the 9th and 10th of August, and the early morning hours of the 14th

of November, observed the spectra of as many as seventy meteors and their trains.

The hand spectroscope described at p. 421, and represented in Fig. 223, is well adapted for these investigations ; but a still better instrument is that drawn in Fig. 285, specially constructed by Browning for his own use in the observation of meteors, in which the apparent angle caused by the velocity of the meteor is diminished, and which, on account of the large field of view, greatly facilitates observation.

This instrument consists of a direct-vision compound prism P, and a plano-concave cylindrical lens L. M_1, M_2, M_3

FIG. 285.



Browning's Meteor Spectroscope.

denote three successive places in the flight of a meteor, and m_1, m_2, m_3 show the path of the rays from the meteor to the lens L, while the dotted lines indicate the course taken by the rays in their passage through the refracting media. The ray m_1 reaches the eye viewing it through the prism at the same moment as the ray m_3; the eye, therefore, commands the large space in the heavens included between M_1 and M_3, and can observe any meteor shooting over that space without the instrument being moved. In such a spectroscope the meteor appears to be stationary, and its spectrum can be observed without difficulty. Browning was able with this instrument to observe the spectra of some fire-

balls thrown into the air only a few feet from him. Although the angular velocity of the balls was very great, the characteristic lines of their component metals, barium, strontium, etc., were clearly seen. If a bi-concave lens of longer focus than the cylindrical lens be placed immediately in front of L, and turned towards the heavens, rays of a still greater convergence, reaching beyond M_1 and M_2, will be brought within the range of the eye, and the field of view of the instrument considerably increased.

By directing the instrument to the radial point, Browning succeeded in observing the spectra of several meteors. The spectrum of the nucleus was generally continuous, presenting all the colours of the solar spectrum excepting violet. In certain instances yellow preponderated; in others the spectrum presented one homogeneous yellow hue, though nearly every other colour, from red to green, was faintly visible. In two instances the spectrum was of a homogeneous green tint. The chief difference remarked between the August and November meteors was in the spectrum of the train; in most of the August meteors this consisted of one yellow line of intense brilliancy, comparable to the line of glowing sodium, which manifested the presence of luminous gas. In the November meteors the spectrum of the train was broad and continuous, and pale in colour. The light, which was mostly blue, green, or steel-grey, appeared in general to be homogeneous; but this appearance might arise from the light being too weak to yield a visible spectrum, as in the case of stars below the second and third magnitude, where the red and blue rays are wanting in the spectrum, though doubtless present in the light of the star. The yellow line given by the train of the August meteors was altogether absent in that of the November meteors.

The November shower of 1868 was observed by Secchi. Among the numerous meteors leaving a train of light behind

them was one the light of which lasted fifteen minutes, and was at first sufficiently bright for examination by a prism. Secchi found the spectrum to be discontinuous, and the principal bright bands and lines were red, yellow, green, and blue. Secchi had also the good fortune to see two meteors in the spectroscope; the magnesium line appeared with great distinctness, besides which some lines were also seen in the red.

Among the recent observers of meteor spectra, Konkoly deserves a prominent place. He finds that the head of the meteor usually gives a continuous spectrum, upon which is frequently—but by no means invariably—seen projected the bright sodium lines. He is, therefore, of opinion that sodium is not always an integral constituent of the meteor, but is found floating in the air, and becomes incandescent with the meteor. Since, however, the sodium particles must obviously decrease in number in proportion to their elevation above the earth, it may sometimes happen that a meteor containing no sodium, if observed at a great height, may show no sodium lines. Konkoly has been confirmed in this view by the fact that in observing the same meteor the spectrum has at first appeared without the sodium line, while afterwards it was very brilliant. It must not, however, be forgotten that comets exist, as shown by the comet Wells of 1882, in which incandescent sodium plays a very important part. As there can be no doubt that meteors and comets stand intimately related to each other, the possibility must be admitted that in some meteors incandescent sodium may be present.

PART EIGHTH.

RESULTS OF THE SPECTROSCOPIC INVESTIGATION OF THE ZODIACAL LIGHT, AURORA BOREALIS, AND LIGHTNING.

RESULTS OF THE SPECTROSCOPIC INVESTIGATION OF THE ZODIACAL LIGHT, AURORA BOREALIS, AND LIGHTNING.

94.—THE ZODIACAL LIGHT.

AFTER sunset on a clear evening in spring there may sometimes be observed in the western sky a faint cone of light proceeding from the place where the sun has set, and extending along the ecliptic, occasionally as far as the Pleiades. In September and October a similar cone of light may be seen in the eastern sky before sunrise. This faint light (Fig. 286), to be seen nightly in the tropics, is known as the zodiacal light, on account of its extending in the direction of the zodiac or ecliptic. This light has manifestly some connection with the sun, and is supposed to emanate from a flat ring surrounding the sun, of small eccentricity, and lying between the orbits of Venus and Mars. Jones and Heis, by whom the phenomenon has long been carefully observed, are opposed to the theory that it is produced by a nebulous ring circulating round the earth within the orbit of the moon, and shining by its own or reflected light; while Liais has no hesitation in regarding it as an extension of the corona. Opinions are thus very diverse as to the true nature of this phenomenon, and it is therefore all the more interesting to ascertain the verdict of the spectroscope. Notwithstanding the extreme faintness

of the light, it suffices to form a spectrum which Liais observed to be continuous, thus proving the source of light to be non-gaseous. Ångström and Respighi found that not only was there a continuous spectrum as far as F, but that the green corona line (1247 K.) was undoubtedly present.

FIG. 286.

The Zodiacal Light in the Evening Sky.

On the 4th, 5th, and 6th of March, 1872, the spectrum of the zodiacal light was observed by Vogel with a pocket spectroscope. He found it to consist of a faint green band bounded towards the red by a line of somewhat greater intensity. By the use of a larger instrument the place of the line was accurately determined, and was found to have a wave-length of 557·1 millionths of a millimetre.

A. M. Wright has devoted himself very assiduously to the spectroscopic investigation of this phenomenon; he finds the spectrum to be continuous, and to differ in no respect from that of faint daylight or twilight. It extends approximately from D to G, but in this respect varies with the clearness of the sky, and diminishes in brightness at both ends. The bright line in the green was occasionally seen, but was regarded by Mr. Wright as belonging to aurora. From this it would appear* that the zodiacal light is only reflected sunlight from a ring of fine particles, by which the sun is surrounded, extending beyond the orbit of the earth. The polariscope gives similar testimony, as it shows the existence in the zodiacal light of rays that are polarised in a plane passing through the sun. As to the nature and physical constitution of the ring supposed to exist between Venus and Mars, nothing certain is known. This light offers to the astronomer a wide field of research, in which not only patience and perseverance are needed, but also a sufficiently clear sky.

95.—The Spectrum of Aurora.

The aurora borealis, although by no means a rare phenomenon, is one of the most mysterious appearances to be observed in the heavens. In the moderate latitudes of Central Europe it occasionally appears in great splendour, but never in these regions approaches in magnificence the glory it displays in the arctic regions. Upon the nature of aurora physicists are by no means agreed, and even its height above the surface of the earth is an unsolved problem. While some regard its distance from the earth to amount to several miles from the wide extent of the earth's surface over

* [This opinion must be received with caution.]

which the same aurora is sometimes seen, others maintain upon good evidence that it occasionally descends to the tops of mountains, or to the level of high plains. Some observers regard aurora as a celestial phenomenon; others regard it as of telluric origin, and speak of a "magnetic" or "electro-magnetic storm," without giving to the term any definite meaning. Great auroral displays are often announced by disturbance of the magnetic needle, and this disturbance occurs simultaneously over a large part of the earth's surface. Strong currents of electricity (earth currents) are sometimes developed in the earth to such extent that the telegraph lines of a whole country are affected; and these currents are so powerful that it often requires all the batteries at a telegraph station to be joined together to overcome them.

From the observations of Professor Fritz, of Zürich, it appears that the occurrence of aurora is subject to maximum or minimum periods of $11\frac{1}{9}$ years. The same periodicity is shown in solar spots, and it is very remarkable that when the solar spots are numerous, aurora is of frequent occurrence, while in years when there are few solar spots, aurora is infrequent, and faint in character.

Ångström seems to have been the first to observe the spectrum of aurora; his observations date from the winter of 1867-68. He saw only one bright line situated to the left of the well-known calcium group of the solar spectrum. With a wider slit, he observed also traces of three very faint bands extending nearly to the F-line, and once during the undulations of a very flickering arch, faint lines were visible. The same line was observed by Ångström during several consecutive nights, in March 1867, at Upsala, and its wave-length estimated at 0·0005567 of a millimetre; it is not coincident with any known line of a terrestrial element.

This line is introduced into Ångström's spectrum of the telluric lines, as a dotted line between δ and E at 556 (Plate XI.)

The observations of D. K. Winder show a bright line in the yellow close to D, and coincident with one of the dark lines appearing in the solar spectrum when the sun approaches the horizon; a fainter line in the green was sometimes visible, and on one occasion a line in the red.

Similar observations were made on the 15th and 16th of April, 1869, by Rayet and Sorel; the spectrum showed the characteristic auroral line, and the atmospheric lines.

On the 6th of October, 1869, the spectrum of aurora was examined by Flögel. With a moderate opening of the slit the yellow line was alone visible. When the slit was opened as much as 1·3 millimetre, a faint diffused band in the green made its appearance, which seemed to extend as far as the F-line, and could not be concentrated into a line by contraction of the slit. No such faint band was perceptible in the red, proving that no stellar light had found its way into the slit.

On the 5th of April, 1870, observations were made at Lennep (Rhenish Provinces) by A. Schmidt. The yellow line was remarkably bright and broad, and varied in intensity, at times appearing very faint, and immediately afterwards shining out with great brilliancy. From the neighbourhood of this line to F, there stretched a continuous band, which frequently became resolved into three lines, bright, though fainter than the first line.

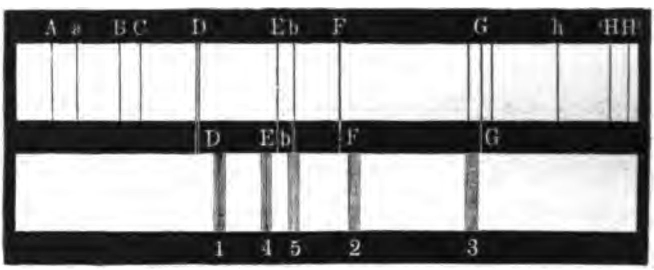
Fig. 287 gives the spectrum of aurora as observed, on the 21st of October, 1870, by Lord Lindsay, at Dun Echt, with a direct-vision spectroscope, and below is given the solar spectrum. The respective brightness of the lines is indicated by the numbers from 1 to 5.

On the 24th of the same month a magnificent display

of aurora was visible over the greater part of Europe, extending over the northern and western portions of the sky. Upon the luminous red background appeared three deep red streamers very sharply defined. On the following day the phenomenon offered the rare spectacle of an ***auroral crown.*** The crimson streamers, crossed by white rays, converged to a point a little south of the zenith.

Professor Förster, of Berlin, found the spectrum to consist solely of the narrow greenish-yellow band, the position of which has been determined by Ångström. In the un-

FIG. 287.



Spectrum of the Aurora Borealis as observed at Dun Echt by Lord Lindsay.

illuminated portions of the sky the spectroscope showed the characteristic auroral line, and this had been noticed on previous evenings when no trace of aurora was visible.

On the same evening, at Guildford, Capron observed a very bright line in the green, visible in all parts of the sky, but most brilliant in the silver-white rays. There was also a much fainter line in the red, approximating to the lithium line.

An observer at St. Mary Church, Torquay, describes the spectrum as consisting of four lines : a strongly marked red line between the lines of lithium and calcium near C, a pale

yellow line near D, a paler one near F, and a still fainter one beyond; there was also a faint continuous spectrum extending from D to beyond F. It seemed as if two spectra were superposed, one consisting of the four lines and the faint continuous spectrum, the other given by the remaining light, including the greenish line near D.

Gibbs, observing in London, saw only a line in the red very similar to the C-line ($H\alpha$), and another line in the green.

Elger, at Bedford, observed a red band near C, a bright band near D, apparently the characteristic line of aurora, and a faint and ill-defined line near F, as well as an exceedingly

FIG. 288.

Spectrum of the Aurora Borealis as observed by Zöllner.

faint line about midway between F and D. The red band was absent from the spectrum of the white rays of the aurora, whereas the remaining three lines were always visible. These observations seem to show that different rays of aurora produce different spectra.

Fig. 288 gives the spectrum as observed by Zöllner at Leipzig, with a miniature spectroscope. In order to collect sufficient light, the slit was opened tolerably wide; and for the purpose of securing an approximate estimate of the position of the lines, those of lithium and sodium were produced simultaneously by means of a spirit lamp. The line (2) in the green, probably the characteristic auroral line, was brilliant in every part of the aurora; the red line

(1) was only well seen when the instrument was directed to the red portions of the sky. The faint blue bands α, β, were only occasionally seen, the most striking being the broad dark band β as it appeared against a bright background.

The ill-defined *bright* bands near F, and a little beyond it, are regarded by Zöllner as the remains of the continuous spectrum which has been broken up by the *dark* absorption bands α, β.

In the same spectroscope Zöllner subsequently observed the spectra of hydrogen, nitrogen, oxygen, and carbonic acid, and was convinced that the red line (1) was not coincident with the brightest parts in the spectra of any of these four gases It is more refrangible than the red hydrogen line Hα, and may possibly lie near the group of telluric lines α (Plate XI.), between C and D, the mean wave-length of which is 0·0006279 of a millimetre.

The magnificent aurora visible in Central Europe on the 4th of February, 1872, was observed by Dr. Schellen at Cologne. The spectrum was similar to that obtained by Zöllner, except that the bright spot described by him as the first narrow zone of light—to the left of α—extended without break or variation as far as the bright line 2. But wherever the spectroscope might be directed the very intense green line of aurora was always visible. With a somewhat wider slit a faint flush of light proceeded from this line towards the blue, traversed by two dark bands. By narrowing the slit the three bright bands could not be reduced to sharp lines, so that the spectrum always preserved the appearance of a continuous band of light traversed by the dark absorption bands, of which the broadest and darkest was the one furthest removed from the green line. On one occasion, a momentary glimpse was obtained of a red line as the instrument was, for an instant, directed on

to an intensely red spot in the eastern sky, and the eye-piece so turned as to exclude the green line from the field of view. The comparison spectra employed were those from a spirit lamp impregnated with salt, and from hydrogen in a Geissler tube.

The position of the green auroral line was estimated from the sodium line, while the position of the extreme band was shown, from the hydrogen line $H\beta$, to lie somewhere between *b* and F.

The spectrum of the aurora of the 14th of October, 1872, was observed by Professor Holden at West Point. He

FIG. 283.

Spectrum of the Aurora Borealis as observed at West Point, by Holden.

first directed his pocket spectroscope upon the full moon to ascertain the length of the spectrum which extended from M to N. The instrument was then directed, with a wide slit, upon the aurora, and a careful drawing made of the position of the lines. The violet rays (left) appeared cut off, and the spectrum consisted (1) of a broad, bright, red band R, (2) of a dark space of similar breadth B, (3) of a green bright band G, almost equally broad, (4) of a faint spectrum of diffused light, (5) of a bright line 1 in the blue, followed by a second bright line 2, somewhat more refrangible. When the aurora faded the green line alone remained visible, with scarcely a trace of the blue one.

In 1871 Vogel instituted measures of the bright lines in the spectrum of aurora with the following results:—

Wave-lengths in Millionths of a Millimetre.	Remarks.	
629·7.	Very bright red bands.	Upon a faintly luminous background.
556·9.	Brightest line in the spectrum.	
539.	Excessively faint line, observation uncertain.	
523·3.	Tolerably bright line.	
518·9.	This line is very bright when the red line appears at the same time; otherwise it agrees with the preceding lines in brightness.	
500·4.	Very bright line.	
469·4. 466·4. 462·9.	Bright band of light, somewhat less bright in the middle. Very faint in the portions of the aurora in which the red line appears.	

A catalogue of the lines hitherto observed in the spectrum of aurora has been made by Rand Capron.* The following are the wave-lengths given in ten millionths of a millimetre:—

6297. Very bright band, first noticed by Zöllner, seen only in red aurora, standing on a dark background, sharply defined with no other line near. According to Vogel, when this line is bright, 5189 is bright also.

5567. The splendid line in the yellow-green, brightest of all, not always equally brilliant, but always well defined. According to Capron, coincident with a very faint atmospheric line, but needing confirmation.

5390. Very faint, seen only by Vogel, though possibly also by Alvan Clark.

5233. Moderately bright, according to Vogel; frequently visible.

5189. Very bright when the line 6297 is also visible, not so frequently seen as 5390.

5004. Very bright, according to Vogel, possibly coincident with a nitrogen line visible in the spectrum of nebulæ.

* J. Rand Capron, *Auroræ, Their Characters and Spectra.* London and New York, 1879.

4850. Line in the blue; position given by A. Clark, not seen by Vogel, nor by any one in Europe.

4694. }
4663. } Bright band, somewhat less luminous in the middle, very faint in that portion of the aurora in which the red line appears (Vogel).
4629. }

4350. Observed by Clark, position uncertain, tolerably bright, not seen by Vogel. Considered by Lemström to be more refrangible than G.

It thus appears that hitherto nine bright lines have been seen in the spectrum of aurora, but never all visible at once, or seen by the same observer.

From the mean of subsequent observations, Vogel determined the wave-length of the brightest line to be 557·08 millionths of a millimetre, which agrees with Winlock's previous estimation of 557·1. At this spot there also occurs a bright line in the spectrum of the solar corona, and for a considerable time they were regarded as identical, but the researches of Young have proved that this is not the case. Vogel is of opinion that this brightest line of aurora is to be identified with a very faint line in the spectrum of nitrogen. The fact of this line appearing isolated, and with great intensity, in the spectrum of aurora, is not regarded by Vogel as inconsistent with the great variability of gas spectra under different conditions of pressure and temperature. He is, however, strongly inclined to the opinion that the spectrum of aurora is merely a modification of that of air.

Ångström is not in accord with Vogel in the identification of the bright auroral line with a band in the spectrum of rarefied air; according to him the greenish yellow portion of the air spectrum consists of seven bands of nearly equal intensity, and the bright line coincides only with the edge of one of these bands. Piazzi Smyth is equally doubtful as to the identification of this line either with hydrocarbon or with iron, and regards its nature as completely unknown. "There is reason for supposing," remarks Ångström, "that

the spectrum of aurora is composed of two different spectra which in all probability are diverse in their origin. The one spectrum is formed by the characteristic yellow light which is visible even in the faintest trace of aurora, and is sometimes to be seen in every part of the heavens on a bright winter night. The other spectrum consists of exceedingly faint stripes and bands, which are only bright enough to be measured during a very remarkable display."

With regard to this second spectrum, the observations are much at variance. This may possibly be due to variability in the phenomenon itself, according to the elevation at which it takes place; if in the higher regions of the air, there is no damp, and the electricity can only be conducted by the oxygen and nitrogen. Ångström found that when two platinum wires were introduced into a bottle the base of which was covered with a stratum of phosphoric anhydride, and the air exhausted to the pressure of a few millimetres, upon the application of an induction current the bottle was filled with the violet light which usually appears only at the negative pole. The spectrum of this light consists of three yellow lines, of which the wave-lengths are respectively 427·2, 470·7, 522·7 millionths of a millimetre, which coincide satisfactorily with the three lines of aurora, the wave-lengths of which deduced from the mean of the measures taken by Barker, Vogel, Ångström, and Lemström are respectively 428·6, 470·3, 522·6. In the spectrum of aurora Vogel also detected in the neighbourhood of the line 469·4 two faint bands of light in the violet, having a wave-length of 466·3 and 462·9, besides two corresponding dark bands of which the wave-lengths were 465·4 and 460·1.

When aurora is flickering there is reason for supposing that the electric tension is discontinuous, in which case the strongest line in the air spectrum, the green line, wavelength 500·3, ought at least to appear. This line has, in

fact, been carefully observed by Vogel, and seen also by Ångström and others. Finally, when an aurora is visible in the lower regions of our atmosphere, its spectrum may include lines of hydrogen, as also the strongest bands of the channelled spectrum of our atmosphere, as, for instance, the one situated at 497·3. In accordance with the above assumption, nearly all the lines and bands of aurora, the positions of which have been with any certainty ascertained, are to be found in the spectrum of rarefied air. "It may, therefore, be generally assumed that the faint bands in the spectrum of aurora belong to that of the negative pole, and that the variations noticed in the spectrum are due to the introduction of parts of the air spectrum, either as lines or shaded bands." This does not, however, explain the existence of the yellow line, and Angström is, therefore, led to suppose that it may be due to fluorescence or phosphorescence.

"This supposition derives some support from the fact that many observers have remarked the subsidence of the yellow line when red was visible in the spectrum, and in apparent connection therewith the simultaneous decrease in brightness of the violet and ultra-violet portions. Oxygen, too, is known to be phosphorescent, as well as several of its compounds, among others protoxide of nitrogen."

Zöllner is of opinion that if the light developed in aurora is of an *electric* character, analogous to that exhibited by gases rendered incandescent in an exhausted tube, this must take place at so low a temperature, that it would not be possible at a similar temperature to observe the spectrum of gases in a Geissler tube. The want of coincidence between the spectrum of aurora and that of any known spectrum of the atmosphere may be explained by the spectrum being of a different order from that of any atmospheric spectrum which is capable of artificial production.

The spectroscope has, therefore, been unable to give any decisive verdict as to the constitution of aurora, and further research is necessary before this can be looked for.

96. The Spectrum of Lightning.

From the close connection between lightning and the electric spark, it was to be anticipated that a flash of lightning would yield a spectrum closely allied to that of the ordinary electric discharge when passed through the air, and that it would therefore consist of the bright lines belonging to the atmospheric air, pre-eminently those of nitrogen. This proved to be the case when flashes of lightning were observed by Lieut.-Colonel Herschel through a hand spectroscope. Among the numberless bright lines visible, the blue nitrogen line was the brightest; the red line of hydrogen, Hα, was also recognized. Besides this spectrum of lines, a bright continuous spectrum was likewise present.

The ordinary spectrum of lightning produces the impression of green and blue, or rather of greenish-blue; but as in bright flashes all the prismatic colours are visible, it must be supposed that the part between the lines E and F is so much brighter than the rest as to cause the impression of those colours to predominate in the spectrum. The variation of relative brightness of the continuous spectrum and of the spectrum of lines is very surprising; at times the lines are scarcely visible, and at other times they form nearly the whole spectrum. The difficulty of distinguishing the many fainter lines is considerable, owing to the instantaneous character of the phenomenon.

The most complete observations that have yet been made are those by Professor Kundt, of Zürich, by whom upwards of fifty flashes of lightning have been observed with a pocket spectroscope. In addition to the spectra consisting of bright

lines, there always appeared other spectra formed of a great number of fainter bands, somewhat broader than the lines, and disposed regularly at equal intervals one from another.

The spectra of lines consisted of one and sometimes of two lines in the extreme red, a few very bright lines in the green, and some less bright in the blue, besides a still greater number much fainter, most of which were sharply defined. The spectra of the flashes differed widely, for certain lines which were very brilliant in one flash were entirely absent in another, being replaced by a set of lines invisible in many other flashes.

The banded spectra were quite as dissimilar, the coloured bands in some flashes appearing in the blue and violet, in others in the green as well, and occasionally only in the red.

In most cases each flash presented only one of these spectra. The spectra of lines were usually given by the forked flashes, while sheet lightning gave banded spectra. In only two cases did the same flash first give a bright line spectrum very sharply defined and then suddenly show a band spectrum evenly distributed throughout.

The two kinds of spectra correspond with the colours in which lightning appears to the eye, forked lightning being usually white, while sheet lightning inclines to red, violet, or blue. This is in conformity with the different colours exhibited by electrical discharges, according as they appear as a spark or a brush of light. The light of a spark discharged into the air is always more or less white according to the nature of the bodies between which it passes, whilst the colour of the electric brush is red or violet, and that of the electric glow is violet or bluish. The spectrum of the spark is always one of lines, while that of the brush or glow discharge is one of bands.

In September, 1871, the position of the brightest lines in the spectrum of lightning was accurately determined by

Vogel and Lohse, with the stellar spectroscope at the Bothcamp Observatory. The width of the slit was such as to show the sodium lines separated. The evanescent character of the phenomenon rendered observation difficult, but the amount of error in the wave-length given is not thought by the observers to exceed 0·5 millionth of a millimetre. The lines measured are as follows :—

534·1.	Faint line.
518·4.	Tolerably bright line.
500·2.	Very bright line, before a fainter one.
486·0.	Bright line.
From 469·3 to 458·3.	Broad band.

In the neighbourhood of G was a second broad band of light. The lines in the red were too faint for measurement. Line No. 1 occurs in the spectrum of oxygen; 2, 3, and 5 are identical with lines found in the spectrum formed by the electric spark, when passing through air; 4 is coincident with the bright line Hβ in the spectrum of hydrogen.

This line spectrum was not produced by every flash; in some cases the bright lines were visible upon a continuous background, while in others a continuous spectrum appeared in which no lines were traceable. The line spectra were not always identical; in some instances the bright lines extended as far as the red, n others they were confined to the blue and green.

In the year 1878 a series of observations was made upon the spectrum of lightning in Colorado, by A. Schuster. In order to secure the greatest accuracy he restricted himself to the portion of the spectrum between the wave-lengths 500 and 580 millionths of a millimetre, which includes nearly the whole of the yellow and green. The instrument employed was a direct-vision spectroscope with adjustable slit; the measurements being taken by a bright line in the

chief focus of the telescope (see Fig. 45). The slit was sufficiently displaced to bring the line to be measured in coincidence with the bright line which extended as far as the middle of the field. The measures were always taken at night, and the spectroscope left undisturbed till the morning, when the neighbouring Fraunhofer lines were measured, and the position of the bands determined by interpolation. The adjustment in position cannot naturally take place during the instantaneous illumination of a flash of lightning, but during the repeated occurrence of the flashes the adjustment may gradually be made more exact, until complete coincidence is obtained. By this means an observer may obtain several readings for each band. Schuster also comments on the variability of the spectra, being sometimes linear and sometimes continuous, or consisting of bands. The following is the result of his measures :—

Band.	Wave-length.
α	559·2.
β	533·4.
γ	518·2.
δ	516·0.

The bands β and γ are identical with those previously observed by Vogel; α and δ could only be determined on a single occasion. The conclusion arrived at by Schuster as the result of his observations of the band spectrum of lightning is that this spectrum resembles that obtained at the negative pole of a vacuum tube filled with oxygen, in which a trace of carbonic oxide has been left.

These investigations lead to the conclusion that the difference in the spectra of lightning depends upon the mode in which the electricity of the atmosphere is discharged, whether through the earth or between the clouds. When an electric cloud discharges itself into the earth, the discharge occurs at a state of high tension, and, accompanied

by a great development of heat, darts to the ground in the form of a forked flash, passing on its way through the atmospheric air, that is to say, through a gaseous mixture of oxygen, nitrogen, watery vapour, and carbonic acid. According as one or other, or several of these gases are raised by the flash to a glowing state, the spectrum of the lightning assumes a different form. When the discharge takes place from one cloud to another, it may occur in the form of a brush. In this case, both clouds being pointed and indented, any high degree of tension cannot be attained, and the current frequently passes as a rapid succession of discharges which take the form of a brush of light. The various kinds of electrical discharges are accompanied by a corresponding variety in the report; if in the form of a spark, a single sharp crack is heard; the brush discharge is never accompanied by a single clap, but always by a hissing or rushing noise, with a series of faint cracks in rapid succession; the glow discharge is noiseless.

APPENDICES.

APPENDIX A.

To page 41.

REFRACTION THROUGH A PRISM.

The course of a ray in its passage through a prism and its consequent deviation is determined by the size of the angle of incidence formed with the first surface of the prism. In Fig. 290, let B A C represent a prism, ϕ the refracting angle, D e the incident ray, $e\ h$ the path of the ray through the prism, and h E the emergent ray, $f\ e\ b$ and $g\ h\ b$ the perpendiculars at the points of incidence e and h.

Let x be the angle of incidence on the first surface A B of the prism, and y the corresponding angle of refraction; let y_1 be the angle of incidence (inside) on the second surface A C of the prism, and x_1 the angle of refraction (outside). Now, it is evident that in the triangle $e\ b\ h$ the outer angle $z = y + y_1$. And as the sides of the angle z are perpendicular to the sides A B and A C of the refracting angle ϕ, $z = \phi$, and therefore $y + y_1 = \phi$: that is to say, the sum of the two angles formed within the glass by the ray and the perpendicular is equal to the refracting angle. If, therefore, one of these interior angles y and y_1 should either increase or diminish, the other must also increase or diminish to the same amount.

Further, the total deviation a suffered by the ray in its path through the prism is equal to the sum of the two deviations taking place at the two surfaces; thus :—

$$a = (x - y) + (x_1 - y_1),$$
$$\text{or } a = (x + x_1) - (y + y_1), \text{ and as}$$
$$y + y_1 = \phi, \text{ so also}$$
$$a = x + x_1 - \phi;$$

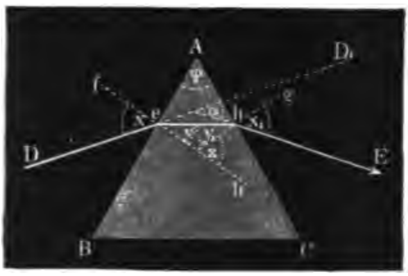
that is to say, the defraction suffered by a ray in its passage through a prism is equal to the sum of the two external angles of incidence x and x_1 minus the refracting angle of the prism. Fig. 23 (p. 44) represents a prism mounted so as to allow of a continuous revolu-

tion round its refracting edge, whereby the angle of incidence x being constantly changing in reference to the first refracting surface, the amount of deviation of the rays passing through the prism is also constantly varying. But it is found by experiment that there is one and only one definite position of the prism, and consequently one definite value of x, in which the deviation of the ray is smaller than in any other position—that there is, in fact, a position of *minimum deviation.*

It will be at once seen that the minimum of deviation occurs in the position when the ray *passes through the prism symmetrically.*

In order to convince ourselves of this important proposition, let us suppose that the minimum of deviation does not occur when the angle of incidence is such as to cause a symmetrical course

FIG. 290.



Refraction of a Ray of Light by a Prism.

through the prism, but when the angle x has some other value. In this case x_1 is no longer equal to x, and as obviously no change in deviation is effected by interchanging the angles x and x_1 and y and y_1, it follows there must be a second minimum of deviation answering to the angle of incidence of the value of x_1; this, however, experience entirely contradicts.

Minimum deviation does in fact occur when the ray passes symmetrically through the prism, in which case $x = x_1$ and $y = y_1 = \frac{\phi}{2}$. Therefore the deviation in this instance is

$$a = 2x - \phi,$$

$$\text{consequently } x = \frac{a + \phi}{2}.$$

$$\text{and } \sin x = \sin \frac{a + \phi}{2}.$$

If this equation be divided by the index of refraction μ of the substance of which the prism is composed, the result obtained is as follows: as

$$\frac{\sin x}{\mu} = \sin y = \sin\frac{\phi}{2}$$

$$\sin\frac{\phi}{2} = \frac{1}{\mu} \cdot \sin\frac{a+\phi}{2},$$

$$\text{therefore } \mu = \frac{\sin\frac{a+\phi}{2}}{\sin\frac{\phi}{2}}$$

That is to say, in order to determine the co-efficient of refraction for a prism, it is only necessary to measure the smallest deviation a, and the refracting angle ϕ, which can always easily be accomplished.

APPENDIX B.

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DISPERSION OF LIGHT.

If the index of refraction of the extreme red rays be represented by μ_r, and that of the extreme violet rays by μ_v, then the difference $\mu_v - \mu_r$ may be regarded as the measure of the dispersive power of the prism. The greater this difference is, the greater is the amount of deviation of the violet and the red rays from the original line of incidence.

According to Fraunhofer, these differences and the mean index of refraction for the green rays—as an example—were found to be as follows:—

	$\mu_v - \mu_r$	Index of Refraction.
For a Prism of Water	0·0132	1·3378
For a Prism of Oil of Turpentine . .	0·0233	1·4783
For a Prism of Crown Glass No. 13 .	0·0203	1·5313
For a Prism of Flint Glass No. 30 . .	0·0425	1·6373

With the same angle of refraction, the length of spectra formed by these prisms of various substances is nearly in the proportion

..es given for μ_v and μ_r. The spectrum from a flint sm is double the length of that formed by crown glass, and ·aree and a-half times the length of the spectrum formed . vater prism. Disregarding for the moment the dark lines in . solar spectrum, we obtain in Fig. 32 (p. 61) a clear represen-..ion of the dispersive power of these three substances. With ·ne same angle of refraction a prism of bisulphide of carbon gives a spectrum very much longer than that given by a flint-glass prism, and this even is surpassed by one obtained from oil of cassia.

A comparison of the indices of refraction for various substances for any one coloured ray shows that the dispersive power of prisms of various substances is not proportional to the index of refraction of any one coloured ray. For while between flint and crown glass the difference in dispersive power is as 2 to 4, or as 1 to 2, the mean indices of refraction are nearly as 5 to 6. The dispersive power of a prism of oil of turpentine is greater than that of crown glass No. 13, but the index of refraction of oil of turpentine is considerably smaller.

It has been already remarked that in spectra formed by prisms of various substances, but of the same refracting angle, even when the spectra as a whole are the same length, there is a considerable difference in the spaces occupied by each colour. While the difference $\mu_v - \mu_r$, that is to say, the difference between the indices of refraction for the extreme violet and red rays, gives a true indication of the length of the spectrum as a whole, the difference between the indices of refraction for two selected rays—as, for example, the central yellow and blue rays—forms a measure for the amount of dispersion within these rays, or for the position of these colours in the spectrum. The difference between the extreme rays is called *total dispersion*, while the difference between two selected colours in the spectrum is termed *partial dispersion.* No connection is traceable between the dispersive power of a substance and its index of refraction, nor can any dependence be discovered between the dispersive power of a substance as applied to the whole spectrum and as applied to its separate parts.

APPENDIX C. *To page* 63.

Indices of Refraction for Various Substances.

Refracting Substance.	Density.	Index of Refraction for the Coloured Rays of the Fraunhofer Line.							Observer.
		B	C	D	E	F	G	H	
Merz's Flint Glass	—	1·74056	1·74343	1·75153	1·76233	1·77230	1.79219	—	Van der Willigen.
Fraunhofer's Flint Glass	2·135	1·701050	1·702642	1·707264	1·713134	1·718673	1·728423	1·738154	Dutiron.
No. 13 Flint Glass	3·723	1·627749	1·629681	1·635036	1·642024	1·648260	1·660285	1·671062	Fraunhofer.
Guinand's Crown Glass	2·184	1·611668	1·612624	1·615193	1·618529	1·621274	1·626532	1·630805	Dutiron.
Crown Glass Lit. M.	2·756	1·554774	1·555933	1·559075	1·563150	1·566741	1·573535	1·579470	Fraunhofer.
Crown Glass No. 13	2·535	1·524312	1·525299	1.527982	1·531372	1·534337	1·539908	1·544684	Fraunhofer.
Water (15°R.)	1·000	1·330935	1·331712	1·333577	1·335851	1·337818	1·341293	1·344177	Fraunhofer.
Water (19·5°C.)	1·000	1·33048	1·33122	1·33307	1·33527	1·33720	1·34063	1·34350	Van der Willigen.
Alcohol (17·6°C.)	0·815	1·3628	1·3633	1·3654	1·3675	1·3696	1·3733	1·3761	Baden-Powell.
Oil of Turpentine (8·5°R.)	0·885	1·4704	1·4715	1·4744	1·4783	1·4817	1·4881	1·4938	Fraunhofer.
Oil of Cassia (10°C.)	—	1·5963	1·6007	1·6104	1·6249	1·6389	1·6698	1·7039	Baden-Powell.
Oil of Cassia (14°C.)	—	1·5945	1·5979	1·6073	1·6207	1·6358	1·6671	1·7025	Baden-Powell.
Oil of Cassia (22·5°C.)	—	1·5895	1·5930	1·6026	1·6174	1·6314	1·6625	1·6985	Baden-Powell.
Bisulphide of Carbon (24·2°C.)	—	1·6114	1·6147	1·6240	1·6368	1·6487	1·6728	1·6956	Verdet.

If the index of refraction for the extreme red and violet rays of the spectrum be designated, as in Appendix B, by μ_r and μ_v, then the difference $\mu_v—\mu_r$ may be regarded as the measure of the dispersive power of the prism employed. The greater is this difference in two prisms of different material, but with the same angle of refraction, the greater also is the difference in the amount of deviation of the individual rays. If by the foregoing table we calculate this difference for the extreme rays of the spectrum H (violet) and B (red) in two different substances, as, for instance, in flint glass and water, we shall have

for flint glass, No. 13, $\mu_v—\mu_r = 0·043313$,
for water, $\mu_v—\mu_r = 0·013242$.

The proportion, therefore, between the total dispersion of these substances is 3·270, that is to say, the length of the spectrum given by flint glass is to that given by water as 3·270 to 1, or in other words, the flint-glass spectrum is 3·270 times as long as the water spectrum.

If in the same way this proportion be calculated for the partial dispersion of the intermediate pairs of rays C and B, D and C, E and D, F and E, G and F, H and G, very different results will be obtained, and these will likewise show how much longer any specified portion of the spectrum, as, for instance, that between C and B, is in a flint-glass spectrum than in a water spectrum. If these results be compared, it will be at once apparent that the comparative lengths of individual parts of the spectrum are not proportional to the total length of the spectrum. In the following table this proportion is given for the total and partial dispersion of four pairs of prisms of different substances, but the same refracting angle. For economy of space the indices of refraction are indicated by the Fraunhofer lines to which they correspond; the simple letters refer to the first of the two substances, and the letters with $_1$ added relate to the second substance. The first column of figures expresses the proportion of total dispersion.

Refracting Substances.	$\frac{H-B}{H_1-B_1}$	$\frac{C-B}{C_1-B_1}$	$\frac{D-C}{D_1-C_1}$	$\frac{E-D}{E_1-D_1}$	$\frac{F-E}{F_1-E_1}$	$\frac{G-F}{G_1-F_1}$	$\frac{H-G}{H_1-G_1}$
Flint Glass No. 13 / Water . . .	3·270	2·562	2·871	3·073	3·193	3·460	3·726
Flint Glass No. 13 / Crown Glass No. 9	2·088	1·900	1·956	2·044	2·047	2·145	2·195
Flint Glass No. 30 / Crown Glass No. 13	2·086	1·932	1·904	1·997	2·061	2·143	2·233
Flint Glass No. 23 / Crown Glass No. 13	2·116	1·904	1·940	2·022	2·107	2·168	2·268

APPENDIX D.

To page 117.

Measurement of the Wave-lengths of the different Coloured Rays.

The equation discussed in § 37 presents also a means of determining the wave-length of homogeneous light. If the distance C a_1 of the first dark band from the middle of the central bright band be designated by a_1, then

$$\lambda = \frac{a_1 \cdot s}{E}.$$

The quantities a_1, s, and E may easily be measured, and by their means the value found by calculation of λ, the wave-length of the homogeneous light employed.

In an experiment of this nature Müller obtained the following results: with a width of slit $s = 0{\cdot}015$ inch, and a distance of the screen from the slit $E = 93$ inches, with red light $a_1 = 0{\cdot}15$ inch, and for blue light $a\ a_1 = 0{\cdot}1$ inch. If these numbers are reduced to the foregoing formula, the wave-lengths are

for red light $\lambda = 0{\cdot}0000242$ inch,
for blue light $\lambda = 0{\cdot}0000161$ inch.

The faintness of the image precludes the possibility of measuring the distance a_1 with great exactness; therefore, apart from the circumstance that $a\ a_1$ is not absolutely equal to a C=E, the

values obtained for the wave-lengths by this method cannot lay claim to extreme accuracy. Better results are achieved by the use of delicate instruments for angle measurement, such as theodolites, goniometers, or spectrometers. It will be seen from Fig. 66, p. 113, that in the triangle $a\,c\,d^1$, as the angle

$$a\,c\,d = a_1\,a\,C = \phi_1,$$
$$a\,a_1 = a\,c\,.\,sin\,\phi_1,$$

or if $a\,c$ be again represented by s, and a_1, a_2, a_3 . . . . be taken in the former acceptation,

$$\lambda = s\,.\,sin\,\phi_1.$$

If for the deflected rays $a\,a_2$, $a\,a_3$ . . . . succeeding those marked $a_2\,a_3$ . . . . the corresponding angle of inflection be designated by ϕ_2, then again, according to the foregoing,

$$2\lambda = s\,.\,sin\,\phi_2;\ 3\lambda = s\,.\,sin\,\phi_3, \text{ etc.}$$

If through the telescope of such an instrument the three successive angles of inflection ϕ_1, ϕ_2, ϕ_3, for the first three dark bands be observed and measured, then from these angles and the width of slit the wave-length may be found.

By an observation of this kind when using the orange light due to sodium and a width of slit $s = 1{\cdot}1$ mm. the angle of deflection for the first dark band was found to be $\phi_1 = 0^\circ\ 1'\ 51''$. By these data calculation makes the wave-length of the yellow light of sodium $\lambda = 0{\cdot}0005917$ millimetre, which nearly coincides with the value given for D in the annexed table.

Homogeneous light is to be found in the solar spectrum when the slit is sufficiently narrow, and other precautions are taken, and if the slit be illuminated by different colours in succession, and the foregoing method adopted for the measurement of each colour, the wave-lengths for each separate colour may be obtained. If the velocity of light be divided by the wave-length, the result gives the *number of vibrations* per second of the ether molecules.

The following table gives the wave-lengths in millimetres of the colours corresponding to the Fraunhofer lines of the solar spectrum, and their vibrations per second. As the Fraunhofer lines themselves yield no light, they cannot serve to illuminate the slit; the figures, therefore, in the table were not obtained in the

manner above named, but were computed according to a method which is described in § 39.

Fraunhofer Lines.	Wave-lengths in Millimetres.	Number of Vibrations in a Second.
B	0·0006897	428 billion
C	0·0006559	464 ,,
D	0·0005888	517 ,,
E	0·0005265	578 ,,
F	0·0004856	626 ,,
G	0·0004296	708 ,,
H	0·0003963	768 ,,

If white light be used to illuminate the slit, the image, instead of being composed simply of dark bands alternating with bright bands of one colour, will present the appearance described in § 37, in which, through the overlapping of the various monochromatic images, the dark bands will be no longer black, but appear of a dusky hue bordered by coloured stripes.

APPENDIX E.

To page 133.

ADJUSTMENT OF THE SPECTROSCOPE.

When it is required to identify the kind of light (colour) of a line in any portion of the spectrum, or to register the absorption of a certain colour, not merely in relation to the instrument in use, but to give its absolute place, the methods described in § 27 are quite inadequate. Measurements taken by an arbitrary scale, or by means of a micrometer, or by the angular motion of the telescope, are not sufficient for this purpose. It must be remembered that the dispersion of individual spectroscopes varies greatly, being dependent on the construction and number of the prisms, the size of the refracting angle, and the dispersive power of the substances of which the prisms are composed; consequently the position of any particular coloured line with respect to the other colours of the spectrum may vary considerably in different in-

struments. The only legitimate way of fixing the position of any coloured line is to determine its wave-length.

The following table after Watts gives under *a* the place of the Fraunhofer lines B, D, E, F, and G in the spectra formed by three prisms of different composition—crown glass, flint glass, and bisulphide of carbon—but all of the same refracting angle, 60°; and under *b* the places of the same lines in a diffraction spectrum, supposing in every case the distance between B and G to be divided into 1000 equal parts.

Fraunhofer Lines.	(*a*) Dispersion by the Prism.			(*b*) Diffraction by a Grating.
	Crown Glass.	Flint Glass.	Bisulphide of Carbon	
B	0	0	0	0
D	236	220	194	381
E	451	434	400	624
F	644	626	590	784
G	1000	1000	1000	1000

From this it is evident that the most careful measures of spectrum lines, if derived from the scale or by means of angular measurement, cannot be compared with the results obtained from other instruments, and are, therefore, of secondary value. A registration of the relative position of the lines according to their wave-lengths is subject to no deviation; the positions are invariably the same however the diffraction spectrum may have been produced, or whatever the kind of grating employed.

If, therefore, the results of spectroscopic observations of various observers are to be compared, the observations must be made either with diffraction spectra, or, if made with prismatic spectra in an ordinary spectroscope, the readings of the scale must be reduced to wave-lengths.

The determination of the position of the Fraunhofer lines, and the examination of the spectra of terrestrial substances, have been accomplished mainly by means of diffraction spectra, but as this method always involves the use of a costly grating and a still more costly goniometer, it is not adapted in all cases to take the place of the prismatic spectroscopes now in general use.

The reduction of the readings of the ordinary spectroscope to

wave-lengths is accomplished by means of interpolation, either by calculation from a formula, or, graphically, by comparison with a drawing.

The well-known dispersion-formula of Cauchy forms a basis for the computation of wave-lengths. It expresses the relation between the index of refraction μ of a certain coloured ray and its wave-length λ by the equation

$$\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4},$$

in which a b c are constants, being dependent upon the nature of the refracting medium. If this formula be reduced to its first two terms, the three equations for three different coloured rays will be

$$\mu_1 = a + \frac{b}{\lambda_1^2};\ \mu_2 = a + \frac{b}{\lambda_2^2};\ \mu_3 = a + \frac{b}{\lambda_3^2}.$$

If from these equations the quantities a and b be eliminated, the wave-lengths of these three rays will be expressed:—

$$\lambda_1^2 = \frac{\mu_3 - \mu_2}{\dfrac{(\mu_3 - \mu_1)}{\lambda_2^2} - \dfrac{(\mu_2 - \mu_1)}{\lambda_3^2}}$$

$$\lambda_2^2 = \frac{\mu_3 - \mu_1}{\dfrac{(\mu_2 - \mu_1)}{\lambda_3^2} + \dfrac{(\mu_3 - \mu_2)}{\lambda_1^2}}$$

$$\lambda_3^2 = \frac{\mu_2 - \mu_1}{\dfrac{(\mu_3 - \mu_1)}{\lambda_2^2} - \dfrac{(\mu_3 - \mu_2)}{\lambda_1^2}}$$

By the help of this formula the wave-lengths of an unknown ray, λ_2 for instance, may be found, if its index of refraction μ_2 be known, and if the indices of refraction μ_1 and μ_3 and the wave-lengths λ_1 and λ_3 of two other rays be known also. The first or the third formula is of use when the wave-length of the unknown ray is smaller or greater than either of the known rays—extrapolation; the second formula is used when the unknown wave-length lies between the wave-lengths of the known rays—interpolation.

The foregoing formula would not be of great practical value were it always necessary to determine beforehand the index of refraction of the unknown ray. Nevertheless, it has been remarked

by Mr. W. Gibbs, that if the angular distance between the three spectrum lines in question be not very great, the angles of deviation may be substituted in the equations for the indices of refraction, without introducing any material error in the determination of the wave-length. The quantities μ_1, μ_2, μ_3, may therefore be also obtained by the direct angular measures of the spectroscope if the observed lines are not too far removed from the unknown line, but the results are all the more accurate the nearer the lines in question are to one another. These formulæ will not reduce to wave-lengths observations that are registered by an *arbitrary* scale.

The most convenient method of reducing the results of observation to wave-lengths is undoubtedly an interpolation curve specially constructed for each instrument, in which the equivalents of the readings are given in wave-lengths. For this purpose it is necessary first to find out, by means of a series of careful experiments, the divisions in the scale that correspond to the principal Fraunhofer lines C, D, E, *b*, F, and G, as well as to the best-known and most easily produced bright lines of terrestrial substances, such as thallium, lithium, hydrogen, the air, etc., the wave-lengths of which are well known by direct observation with diffraction spectra. The next step is to take a large sheet of paper, ruled into small squares, the horizontal lines—abscissæ—of which represent the readings of the scale of the spectroscope and the vertical lines—ordinates—the wave-lengths. Upon this the points in which the lines of the scale intersect the corresponding wave-lengths are marked, and these points are to be united by a curve. This forms the wave-length curve for the instrument in question. To ascertain the wave-length of a certain line, the place of which has been read off on the scale, it is only necessary to seek out the corresponding reading on the horizontal line, and to trace it vertically up to the curve. This point gives the wave-length in parts of a millimetre, according to the scale laid down in constructing the curve.

Lecocq de Boisbaudran has published the curve prepared for his instrument with a photographic scale; the wave-lengths are given in millionths of a millimetre with a decimal of one place. The divisions of the scale may be estimated to within about two places of decimals.

Observed Lines.	Divisions of Scale.	Wave-lengths.
Potassium (after Fraunhofer A)	65·55	768·0 after Mascart (middle of both lines).
Potassium (Fraunhofer *a*) .	72·50	718·5 after Ångström.
Potassium (Fraunhofer B) .	77·81	686·7 ,, Ångström.
Lithium	80·78	670·6 ,, Mascart.
Lithium	94·15	610·2 ,, Thalén.
Cadmium	86·25	643·8 ,, Thalén.
Zinc	88·00	636·1 ,, Mascart.
H*α* = Fraunhofer C . . .	83·71	656·2 ,, Mascart, Ångström.
Sodium (Fraunhofer D) . .	100·00	589·2 ,, Fraunhofer (middle of both lines).
Copper	103·25	578·1 ,, Thalén.
Copper	105·90	570·0 ,, Thalén.
Lead	109·00	560·7 ,, Thalén.
Silver	114·00	546·4 ,, Thalén, Mascart.
Thallium	118·40	534·9 ,, Mascart, Thalén, in middle.
Silver	124·40	520·8 ,, Mascart, Thalén, in mid.
Cadmium	130·03	508·5 ,, Mascart, Thalén, in mid.
H*β* = Fraunhofer F . . .	141·75	486·1 ,, Mascart, Ångström.
Cadmium	152·83	467·7 ,, Mascart, Thalén.
Strontium	157·60	460·7 ,, Mascart, Thalén, middle.
Iron	174·28	438·3 ,, Thalén.
Iron	180·80	430·7 ,, Thalén, Ångström.
Calcium	188·25	422·6 ,, Thalén, Mascart.
Indium	200·83	410·1 ,, Thalén.
Calcium (Fraunhofer H_1) .	216·33	396·8 ,, Thalén (C*a*), Ångström (H_1).
Calcium (Fraunhofer H_2) .	220·75 near	393·3 ,, Thalén (C*a*), Ångström (H_2).

It is obvious that the results given by the wave-length curve will be the more accurate the larger the scale upon which it has been drawn, and the greater the number of spectrum lines used in its construction. It is necessary from time to time to subject it to revision, as from the movement of the different parts of the instrument in relation to the scale or to the prism small changes may readily creep in. On this account it is desirable, when the measures are taken with a photographic scale, to have the scale adjustable by a separate screw; it is then easy to bring any division—by preference a round number, 10, 50, or 100—into agreement with any of the lines to be measured, the sodium line D for instance, and thus to test the accuracy of the scale before the commencement of each observation.

APPENDIX F. *Page* 152.

Bunsen's Maps.

The spectra of elements are not always in accordance with those of their chemical compounds; in order, therefore, to ensure the purity of these spectra, it is necessary that the elements themselves should be in a condition of absolute purity when submitted to volatilization. For practical purposes, however, such as the construction of spectrum maps intended to form a standard of reference for the recognition of elements in laboratory work, selection should be made of the chemical compounds that are most volatile and easy of exhibition. Pre-eminent among these are the chlorides; but in every case the drawing of a spectrum must be accompanied by a statement of the form of the compound in which the element was volatilized, and of the kind of heat to which it was subjected.

In the year 1860 the flame spectra of a number of elements were drawn by Kirchhoff and Bunsen, and the position of the bright lines given with respect to the prominent dark lines of the solar spectrum.

Bunsen* has recently reverted to this branch of investigation, and has given great attention to the purity of the elements. His method of procedure is described in § 40. His observations include both the flame spectra and those of the electric spark, and the lines are drawn upon a scale in which the atmospheric lines and the most prominent Fraunhofer lines are also introduced.

The elements of the alkaline group—Potassium, Rubidium, Caesium, Thallium, Sodium, and Lithium—can be much more readily recognised by the flame spectrum than by the spark spectrum. Of the prominent and characteristic lines which form the flame spectra of the chlorides of potassium, rubidium, and caesium, only a faint trace remains when the electric spark is used, and in the case of potassium the disappearance is total. For the recognition of elements belonging to the group of alkalies a Bunsen burner is therefore a necessity.

Of the alkaline earths spectra are given by the chlorides of calcium, strontium, barium, and magnesium, and of other compounds spectra by the oxide of erbium, and the chlorides of erbium, yttrium, cerium, lanthanium, and didymium, besides the very characteristic absorption spectra of erbium (No. 11A) and of didymium (No. 15A).

* *Pogg. Ann.*, vol. 155, pp. 230, 366.

APPENDIX G.

To page 154.

Measurements of the Wave-lengths of the Fraunhofer Lines, by A. J. Ångström.

The first column refers to the scales of Kirchhoff, Hoffmann, and Thalén.

Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.
E	5268·98		5352·43		5434·85
	5272·52		5360·72		5435·44
	5274·27		5361·90		5444·24
	5275·04		5363·97		5445·93
	5279·59		5364·39		5454·70
	5280·92		5366·51		5462·31
	5282·64		5369·01		5463·19
	5286·23		5370·51		5465·61
	5287·61		5372·57		5469·74
	5291·68		5376·56		5472·26
	5292·57		5378·62		5473·29
	5296·07		5380·20		5475·90
	5296·56		5382·33		5477·40
	5297·49		5388·49		5480·15
	5299·96		5389·46		5482·37
	5301·47		5390·59		5486·80
	5302·87		5391·24		5488·91
	5304·98		5392·24		5492·49
	5306·47		5393·49		5493·48
	5307·73		5396·05		5496·60
	5313·00		5397·21		5500·51
	5314·39		5398·26		5501·85
	5315·92		5399·57		5502·76
	5320·48	1391·1	5403·13		5505·12
	5321·29	1389·5	5404·81		5505·85
	5323·35				5507·55
	5327·28	1391·1	5403·14		5509·29
	5329·07	1389·5	5404·81		5511·51
	5330·54		5406·53		5511·81
	5332·01		5408·59		5513·35
	5333·82		5408·98		5515·64
	5335·89		5410·01		5519·50
	5336·93		5412·43		5521·50
	5337·61		5413·40		5523·03
	5339·21		5414·94		5524·67
	5340·24		5416·08		5525·91
	5342·07		5417·92	1280·0	5527·40
	5342·61		5419·48		
	5344·98		5420·12	1280·0	5527·40
	5345·44		5423·56		5529·50
	5347·37		5428·82		5531·63
	5348·61		5431·75		5534·07
	5351·22		5433·03		5536·34

Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.
	5541·96		5662·81		5803·50
	5542·69		5664·53		5804·43
	5545·45		5666·03		5805·82
	5552·65		5674·44		5807·16
	5553·90		5677·94		5808·34
	5557·08		5681·38		5813·14
	5559·26		5683·47		5815·52
	5561·78		5685·54		5821·71
	5562·74		5687·20		5832·49
	5564·64		5689·34		5846·27
	5566·36		5690·60		5847·36
	5568·50		5692·77		5851·34
	5571·68		5693·97		5852·70
	5574·90		5695·46		5854·39
	5577·55		5697·24		5855·24
	5580·80		5700·40		5856·46
	5583·82		5702·58		5858·54
	5585·55		5703·45		5861·42
	5586·65		5705·02		5863·19
	5587·62		5706·00		5865·32
	5589·03		5707·14		5879·00
	5591·18		5708·31		5880·07
	5592·62		5709·91		5882·56
	5593·42		5710·80		5883·03
	5597·17		5713·29		5885·13
	5598·92		5713·95		5886·53
	5600·21		5716·12	D_1	5888·96
	5601·70		5716·84		5891·90
	5604·51		5725·76	D_2	5894·94
	5616·08		5730·50		
	5617·81		5740·88	D_1	5888·98
	5618·49		5746·74		5890·64
	5619·27		5751·95		5891·42
	5623·22		5752·13		5891·96
	5624·36		5753·52		5892·36
	5632·65		5756·06		5894·90
	5634·53		5760·16	D_2	5894·99
	5636·25	1096·0	5761·90		5895·39
	5637·22				5896·94
	5640·21	1096·0	5761·90		5897·26
	5643·05		5771·19		5897·95
	5644·59		5774·07		5898·96
	5647·97		5777·46		5900·38
	5651·60		5779·80		5901·30
	5653·36		5781·25		5902·62
	5654·42		5782·66		5904·41
	5656·71		5784·65		5907·10
1174·2	5657·56		5786·93		5907·98
			5790·16		5909·57
			5792·26		5911·94
1174·2	5657·56		5793·03		5913·15
	5659·63		5796·38		5914·45
	5661·51		5797·25		5917·36

Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.
	5918·94		6055·09		6212·34
	5920·72		6064·50		6214·09
	5921·54		6075·67		6215·46
	5922·83		6077·61		6218·25
	5923·86		6081·91		6220·88
	5927·21		6083·08		6222·35
	5929·30		6086·50		6225·40
	5931·02		6088·23		6228·13
	5931·60		6090·40		6229·69
	5933·87		6092·24		6231·50
	5934·89		6093·84		6236·11
	5937·28		6095·02		6236·87
	5940·27		6097·48		6237·33
	5941·54		6098·90		6239·20
	5943·45		6101·74		6240·29
	5944·81		6104·40		6242·38
	5945·80		6107·18		6243·27
	5947·45		6109·93		6245·40
	5948·27		6115·32		6246·33
	5950·24		6118·74		6251·54
	5951·79		6121·15		6253·18
	5953·73		6123·73		6255·29
	5955·46		6125·10		6257·62
	5957·05		6126·81		6260·15
	5961·49		6128·42		6262·46
	5963·34		6130·40	815·1	6264·09
	5967·17		6135·63		
	5969·04	876·5	6136·63		
	5970·26			815·1	6264·09
	5974·61	876·7	6136·13		6269·13
	5976·05		6140·61		6269·93
	5977·09		6143 89		6276·09
	5982·83		6146·76		6276·86
	5984·17		6148·08		6278·24
	5986·17		6150·48		6279·56
	5987·92		6153·13		6281·58
	5989·71		6153·69		6284·76
	5990·01		6154·21		6286·46
	5996·25		6156·70		6290·07
	5996·89		6160·03		6291·54
	6002·06		6161·20		6294·03
	6007·46		6162·49		6296·71
	6011·23		6163·75		6298·50
	6012 49		6165·42		6300·79
	6015·62		6168·28		6301·64
	6019·14		6169·39		6309·54
	60?0·72		6172·29		6313·93
931·4	6022·97		6174·30		6316·92
			6175·74		6318·16
931·4	6022·97		6179·25		6321·56
	6025·95		6187·05		6334·29
	6041·18		6190·50		6335·91
	6053·08		6199·64		6337·96

Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.
	6343·15		6542·96		5191·65
	6346·09		6545·12		5190·53
	6354·03		6547·58		5188·18
	6357·67		6549·79		5187·35
	6361·16		6551·50		5185·10
	6364·23		6555·91	b_1	5182·96
	6377·32		6557·30		5182·61
	6379·73		6558·14	b_2	5172·02
	6392·61		6559·51		5171·06
757·0	6399·02	C	6561·81	b_3	5168·34
			6567·91	b_4	5166·74
			6571·09		5179·52
757·0	6399·02		6573·76		5178·13
	6407·12				5176·38
	6410·12	E	5268·98		5175·59
	6413·84		5267·23	b_2	5172·02
	6415·64		5265·77		
	6418·90		5264·52		
	6420·36		5263·35	b_4	5166·75
	6429·85		5262·44		5165·74
	6431·46		5260·95		5164·59
	6438·08		5259·63		5161·62
	6449·00		5254·06		5158·50
	6453·82		5252·45		5155·06
731·7	6461·70		5251·00		5153·08
	6463·46		5249·66		5152·55
	6466·86		5248·45		5151·26
	6468·50		5246·28		5150·14
	6470·47		5242·71		5147·49
	6471·57		5241·52		5145·73
	6474·57		5239·01		5144·50
	6478·73		5236·30		5142·02
	6480·90		5234·38		5141·23
	6482·51		5233·58		5138·64
	6488·40		5232·10		5136·79
	6489·79		5229·00		5132·96
	6492·13		5227·49		5130·83
	6492·72		5226·24		5128·60
	6493·90		5224·28		5126·67
	6494·84		5217·14		5125·47
	6496·03		5216·50		5124·40
	6497·97		5215·50		5123·18
	6501·51		5214·36		5121·04
	6511·36		5209·45		5119·94
	6513·90		5207·64		5114·87
	6515·53		5205·23		5112·32
	6517·32		5203·74		5109·80
	6518·28		5201·53		5108·84
	6522·87		5199·73		5107·02
	6531·47		5197·92		5104·93
	6532·95		5197·03		5103·63
	6535·96		5195·18		5102·20
	6541·18		5194·09		5099·05

Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.
	5098·14		4982·59		4877·43
	5096·50		4981·82		4875·32
	5090·31		4981·03		4872·94
	5083·54		4979·62		4871·29
	5082.46		4977·80		4870·47
	5081·78		4975·75		4867·51
	5080·64		4972·29		4865·30
	5079·74		4967·30		4863·54
	5078·81		4965·33	F	4860·60
	5077·87		4964·64		
	5075·82		4961·66	F	4860·60
	5074·10	1961·0	4956·73		4859·17
	5071·70				4854·73
	5068·13	c 1961·0	4956·73		4850·90
	5066·37		4954·29		4848·10
	5064·39		4951·96		4842·40
	5059·73		4949·40		4839·16
	5050·97		4945·53		4837·67
	5049·35		4944·55		4835·06
	5047·78		4941·83		4833·25
	5043·40		4938·60		4831·78
1834·0	5041·18		4937·23		4830·20
	5040·14		4936·35		4828·43
			4935·07		4822·76
1834·0	5040·66		4933·41		4819·77
	5038·16		4932·75		4816·93
	5035·33		4931·17		4811·56
	5030·13		4929·47		4809·69
	5028·98		4926·86		4808·03
	5027·29		4924·50		4806·36
	5026·40		4923·06		4804·41
	5025·62		4921·30		4802·33
	5021·75		4919·75		4799·91
	5021·16		4918·17		4799·00
	5019·38		4917·61		4797·57
	5017·62		4916·43		4791·65
	5014·08		4913·21		4788·60
	5013·34		4911·18		4785·77
	5011·42		4907·00		4782·60
	5006·58		4903·94		4778·72
	5005·23		4902·47		4775·53
	5003·07		4899·33		4771·78
	5001·97		4895·82		4770·23
	5001·03		4892·19		4767·45
	4999·72		4890·84		4765·78
	4998·80		4890·05		4764·65
	4997·40		4888·26		4761·54
	4995·91		4886·67		4760·71
	4993·28		4885·88		4756·94
	4990·34		4884·52		4755·22
	4988·32		4883·16		4753·35
	4984·70		4882·88		4751·20
	4983·31		4880·98		4747·22

Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.
	4745·20		4602·64		4493·73
	4743·45		4600·49		4489·40
	4741·77		4599·49		4484·87
	4736·12		4597·24		4483·79
	4732·95		4594·88		4482·99
	4730·83		4591·93		4482·20
	4726·58		4590·80		4480·90
	4723·57		4589·37		4479·27
	4721·41		4585·26		4475·38
	4714·32		4583·25		4472·37
	4713·69		4580·83		4469·42
	4711·86		4579·55		4465·93
	4709·38		4578·26		4463·96
	4708·25		4573·53		4461·10
	4706·49		4571·45		4458·59
2264·0	4702·32		4570·80		4457·69
			4568·52		4455·24
			4567·15		4454·02
2264·0	4702·32		4566·60		4450·35
	4700·83		4564·83		4449·44
	4697·97		4563·20		4446·92
	4690·57		4559·45		4442·24
	4681·26		4558·07		4434·48
	4679·54		4555·33		4431·34
	4677·92		4553·41		4429·85
	4676·80		4551·75		4426·80
	4672·30		4550·20		4424·99
	4667·09	2467·0	4548·88		4422·05
	4666·34				4418·03
	4663·39	2467·0	4548·88		4416·62
	4661·68		4546·47	2670·0	4414·70
	4656·02		4543·89		
	4653·93		4541·76		
	4651·11		4540·22	2670·0	4414·72
	4647·85		4537·81		4407·74
	4645·25		4535·52		4404·20
	4643·19		4533·24		4401·68
	4639·67		4532·06		4400·72
	4638·84		4530·24		4399·58
	4637·16		4528·75		4394·58
	4633·96		4527·99		4393·49
	4632·04		4526·06		4392·97
	4629·63		4524·38		4389·43
	4627·18		4522·92		4388·48
	4624·87		4521·99		4386·79
	4621·64		4519·56		4384·70
	4618·57		4517·81		4382·77
	4616·65		4507·66		4380·44
	4615·42		4501·68		4379·11
	4612·64		4500·69		4375·41
	4610·64		4500·24		4374·17
	4606·67		4498·20		4370·55
	4604·50		4496·14		4369·22

Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.
	4367·52		4269·47		4160·86
	4366·35		4267·71		4158·51
	4362·93		4263·94		4157·42
	4359·06		4261·39		4155·73
	4358·20		4259·99		4153·78
	4355·68		4258·40		4151·52
	4354·52		4255·35		4150·35
	4352·47		4253·87		4148·59
	4351·82		4252·42		4147·09
	4350·82		4250·51		4143·13
	4346·70		4249·78		4141·72
	4344·40		4248·13		4139·25
	4343·06		4246·86		4136·36
	4340·06		4245·17		4133·94
	4336·75		4243·09		4131·52
	4335·10		4241·89		4127·27
	4334·58		4238·72		4125·66
	4332·66		4236·64		4122·82
	4330·04		4235·54		4121·52
2822·0	4325·16		4232·98		4120·56
G	4307·23		4229·14		4118·71
		3040·0	4226·34		4117·77
				h	4101·18
2822·0	4325·16	3040·0	4226·34		
	4322·81		4224·20		
	4320·27		4222·86	*h*	4101·18
	4318·01		4221·69		4097·51
	4316·64		4218·32		4095·59
	4314·58		4216·56		4094·54
	4313·72		4215·31		4091·80
	4312·43		4213·41		4089·73
	4311·70		4209·88		4084·07
G	4307·23		4206·23		4079·55
	4305·28		4204·53		4076·91
	4301·93		4203·27		4076·21
	4300·64		4201·54		4070·96
	4298·54		4200·25		4066·30
	4297·62		4198·11		4062·88
	4296·74		4197·96		4057·18
	4295·00		4196·50		4054·42
	4293·93		4195·40		4051·68
	4292·05		4194·71		4048·13
	4290·67		4191·16		4045·00
	4289·41		4188·47		4040·04
	4288·75		4187·17		4033·85
	4287·44		4186·67		4029·44
	4283·95		4183·52		4024·34
	4282·20		4181·34		4020·16
	4280·48		4178·84		4016·94
	4279·64		4177·09		4004·71
	4276·93		4171·76		4001·36
	4274·59		4166·63		3997·78
	4273·01		4164·94	H^{1}	3967·88
	4271·29		4163·13	H^{11}	3932·82

Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.	Lines.	Mean Wave-lengths.
C	6561·8	B	6888·0		7047·9
	6567·6		6891·2		7146·2
	6571·1		6894·8		7160·4
	6573·6		6898·6	*a*	7163·2
	6580·2		6903·0		7171·5
	6585·5		6907·6		7175·9
	6592·2		6911·9		7179·4
	6592·9		6916·9		7182·7
	6597·1		6922·2		7184·9
	6603·6		6927·7		7189·5
	6632·7		6931·9		7191·2
	6642·5		6936·2		7195·8
	6659·2		6938·4		7198·3
	6662·4		6940·3		7202·7
	6676·9		6945·6		7204·8
	6700·3		6949·2		7213·6
	6702·3		6951·6		7220·0
	6712·9		6954·6		7224·9
641	6714·4		6957·4		7230·4
	6716·4		6959·6		7237·6
	6725·8		6962·2		7242·0
	6760·5		6964·2		7249·5
	6762·9		6969·4		7256·9
	6788·1		6984·2		7262·1
	6818·5		6987·1		7274·3
	6827·6		6992·4		7285·5
	6856·0		6997·4		7289·5
B	6866·8		7003·3	(F)	7300·1
	6869·6		7009·0		7307·1
	6870·7		7014·2		7314·7
	6875·9		7021·6		
	6878·2		7025·0		7600·9
	6882·3	*a*	7034·0	A	±6·6
	6884·7				7625·6

APPENDIX H.

To page 156.

Wave-lengths of the bright metallic lines in ten millionths of a millimetre by R. Thalén.

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Potassium (K).			
Yellow	5829·0	1	
	5802·0	1	
	5782·5	1	
	5353·5	2	broad
Green	5338·5	2	broad
	5322·5	2	
Blue	4827·0	3	broad
Indigo	4309·5	4	
Sodium (Na).			
Orange	6160·0	2	
	6154·2	2	
	5895·0	1	D_2
	5889·0	1	D_1
Yellow	5687·2	3	
	5681·4	3	
Green	5154·8	3	
	5152·5	3	
	4982·5	4	diffused
Lithium (Li).			
Red	6705·2	1	
Orange	6102·0	3	
Blue	4602·7	1	broad
Cæsium (Cæ).			
Green	4971·5	1	
Rubidium (Rb).			
Orange	6296·5	1	
	6204·0	2	
	6160·0	3	
	6070·0	3	
Blue	4776·0	4	
	4569·5	5	
Indigo	4551·0	5	
Violet	4202·0	2	broad
Barium (Ba).			
Red	6526·0	3	
	6496·0	1	
	6483·0	3	
Orange	6449·0	3	
	6343·0	3	
	6140·6	1	
	6109·9	3	
	6062·0	3	
	6018·0	3	
	5991·5	3	
	5971·0	3	
	5904·5	5	
Yellow	5852·5	1	
	5827·0	3	
	5808·5	5	
	5803·5	5	
	5779·5	3	
	5534·2	1	
	5518·4	3	
	5425·0	3	
Green	4933·4	1	
Blue	4899·3	2	
Indigo	4553·4	1	broad
	4524·4	3	
Violet	4165·5	2	
	4130·5	1	broad
Strontium (Sr).			
Red	6550·0	4	
	6501·5	2	
Orange	6407·0	1	
	6387·0	3	
	6380·0	4	
	5970·5	5	
Yellow	5850·0	5	
	5540·0	3	
	5533·5	2	
	5522·5	2	
	5503·5	2	
	5485·0	3	
	5480·0	1	
Green	5256·0	2	
	5238·5	1	
	5228·5	3	
	5225·5	3	
	5223·5	3	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Green (*cont.*)	4967·5	4	
	4961·5	2	
Blue	4876·0	3	
	4872·0	3	
	4831·5	3	
	4812·0	3	
	4783·5	3	
	4740·5	3	
	4721·0	3	
	4607·5	1	broad
Indigo	4305·3	1	broad
Violet	4226·3	3	
	4215·3	1	very broad
	4161·0	3	
	4078·5	1	broad

Calcium (Ca).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Red	6498·0	2	
	6492·1	1	
Orange	6468·5	2	
	6461·7	1	
	6449·0	2	
	6438·1	1	
	6168·3	2	
	6161·2	1	
	6121·2	1	
	6101·7	2	
	5856·5	3	
Yellow	5601·7	4	
	5600·2	3	
	5597·2	3	
	5593·4	2	
	5589·0	4	
	5587·6	1	
	5580·8	4	
	5348·6	2	
Green	5269·4	2	E
	5264·5	3	
	5263·4	4	
	5261·2	5	
	5260·8	5	
	5188·2	3	
	5041·2	2	
Blue	4877·4	3	
	4848·1	4	
	4831·8	5	
	4811·6	4	
	4607·5	4	
	4585·3	4	
	4580·8	4	
	4578·3	4	
Indigo	4535·5	5	s. Titan.
	4534·2	5	
Indigo (*cont.*)	4532·1	5	s. Titan.
	4455·2	5	
	4454·0	1	
	4435·3	5	
	4434·5	1	
	4425·0	1	
	4407·7	5	
	4407·0	5	
	4405·7	5	
	4393·0	4	
	4389·4	4	
	4384·7	4	
	4379·1	4	
	4318·0	2	
	4306·5	3	
	4302·3	1	
	4298·5	3	
	4289·4	2	
	4282·5	2	
	4274·5	5	s. Chrom.
	4271·5	5	
	4253·9	5	s. Chrom.
	4249·8	4	
	4247·5	5	
Violet	4237·5	5	
	4233·0	5	very broad &
	4226·3	1	very strong
	4215·3	2	broad
	4192·5	5	
	4188·5	4	
	4143·0	4	
	4131·5	4	
	4098·0	5	
	4095·5	5	
	4091·8	5	
	4077·0	3	
	3968·0	1	H_1
Ultra-violet	3932·8	1	H_2

Magnesium (Mg).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Yellow	5527·4	1	
Green	5183·0	1	b_1 very
	5172·0	1	b_2 strong
	5166·7	1	b_4
Blue	4703·5	3	broad and
	4586·5	3	diffused
Indigo	4481·0	3	

Aluminium (Al).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6371·0	3	
	6344·5	3	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange (*cont.*)	6244·0	2	broad
	6234·0	2	
Yellow	5722·5	1	
	5695·5	1	
	5592·5	4	diffused
Green	5056·5	1	
Blue	4662·0	1	
Indigo	4529·5	3	broad and diffused
	4511·0	3	
	4478·5	4	
Ultra-violet	3961·0	2	broad
	3943·0	2	
	Beryllium (Be).		
Blue	4572·0	3	
Indigo	4488·5	3	
	Zirconium (Zr).		
Orange	6343·5	3	
	6310·0	3	
	6140·5	1	
	6132·5	3	
	6127·0	1	
Yellow	5384·5	4	
	5349·5	3	
Green	5190·5	3	
Blue	4815·0	1	
	4771·0	1	
	4738·5	1	
	4709·5	1	
	4686·5	1	
Indigo	4497·5	4	
	4494·5	4	
	4443·0	4	
	4380·0	4	
	4370·0	4	
	4360·0	4	
	4242·0	4	
	4241·5	4	
Violet	4228·5	4	
	4209·5	4	
	4209·0	4	
	4155·0	2	
	4149·0	2	
	Erbium and Yttrium (Erb, Yt).		
Orange	6434·0	2	
	6235·5	5	
	6223·5	5	
	6218·0	2	Erb
	6199·0	4	
	6190·0	2	Erb
	6179·0	3	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange (*cont.*)	6164·0	3	
	6148·0	2	Erb and Yt
	6131·5	1	
	6112·5	5	
	6106·0	5	
	6094·0	5	
	6088·0	5	
	6071·5	4	
	6053·0	4	
	6038·0	3	
	6019·0	3	
	6003·0	2	Erb and Yt
	5988·0	2	
	5982·5	4	Erb
	5971·0	1	Erb and Yt
Yellow	5706·5	4	
	5661·0	1	broad
	5646·0	4	
	5641·5	4	
	5629·5	2	
	5604·0	4	
	5594·0	4	
	5588·0	4	
	5580·5	2	
	5576·0	4	
	5567·5	4	
	5555·5	3	Erb
	5544·0	3	
	5542·5	3	
	5527·0	1	
	5522·0	4	
	5509·0	3	
	5502·0	4	
	5496·5	2	
	5479·0	4	
	5477·5	5	
	5476·0	2	Erb
	5473·5	4	
	5468·0	5	
	5465·5	1	
	5437·0	4	
	5401·5	1	
	5352·5	4	
Green	5345·5	4	Erb
	5335·0	3	
	5287·5	4	
	5269·0	4	
	5264·0	4	
	5261·0	4	
	5239·0	4	
	5205·0	2	Erb and Yt
	5200·0	2	
	5195·0	4	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Green (*cont.*)	5134·5	5	
	5126·5	4	
	5121·0	2	
	5117·5	3	
	5087·0	1	Erb and Yt
	4981·5	4	
	4971·0	4	
	4935·0	4	Erb, broad
Blue	4900·0	1	
	4882·5	1	Erb and Yt
	4854·0	1	
	4845·0	5	
	4842·0	5	
	4839·0	5	
	4822·0	4	
	4785·0	3	Erb
	4760·5	4	
	4674·0	4	
	4643·0	2	
Indigo	4505·0	4	
	4422·0	2	
	4397·0	4	
	4374·0	1	Erb and Yt broad
	4357·5	3	
	4309·5	1	broad
Violet	4236·5	3	
	4227·0	5	
	4176·5	2	broad
	4167·0	3	
	4142·5	3	
	4127·0	3	
	4102·5	3	

Thorium (Th).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Yellow	5698·5	5	
	5640·0	5	
	5537·0	3	
	5446·0	3	
	5374·5	3	
Blue	4919·0	3	
	4863·5	3	
Indigo	4392·5	1	
	4381·5	1	
	4281·0	1	
	4277·5	2	
	4272·5	3	

Iron (Fe).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Red	6489·8	3	
Orange	6399·0	1	
	6300·3	3	
	6245·4	2	
Orange (*cont.*)	6229·7	2	
	6190·5	2	
	6135·6	2	
	6064·5	2	
	6023·0	3	
	6019·1	4	
	6007·5	4	
	6002·1	4	
	5986·2	4	
	5984·2	4	
	5982·8	4	
	5976·1	4	
	5974·6	4	
Yellow	5761·9	3	
	5708·3	3	
	5681·4	3	
	5661·5	3	
	5657·6	1	
	5654·4	3	
	5623·2	3	
	5614·5	1	
	5601·7	1	
	5597·2	1	
	5591·2	2	
	5585·6	1	
	5574·9	2	
	5571·7	1	
	5568·5	2	
	5505·9	3	
	5500·5	3	
	5496·6	3	
	5486·8	4	
	5454·7	1	
	5445·9	1	
	5428·8	1	
	5404·8	2	
	5403·1	2	
	5396·1	2	
	5392·3	3	
	5382·3	3	
	5370·5	1	
	5369·0	3	
	5366·5	3	
	5364·0	3	
	5361·9	4	
	5352·4	4	
	5348·6	4	
Green	5340·2	2	
	5339·2	2	
	5327·3	1	
	5323·4	2	
	5315·9	2	
	5306·5	3	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Green (*cont.*)	5301·5	3	
	5282·6	2	
	5280·9	3	
	5269·5	1	E
	5268·5	1	
	5265·8	2	
	5262·4	4	
	5232·1	1	
	5226·2	1	
	5207·6	3	
	5203·7	3	
	5201·5	4	
	5194·1	3	
	5191·7	2	
	5190·5	4	
	5171·1	4	
	5168·3	3	b_3
	5166·7	2	b_4
	5161·6	4	
	5138·6	2	
	5107·0	3	
	5064·4	4	
	5051·0	2	
	5049·4	2	
	5041·2	3	
	5040·1	3	
	5005·2	4	
	5002·0	5	
	4993·3	5	
	4990·3	4	
	4988·3	5	
	4956·7	1	strong
	4923·1	3	
	4919·8	1	
Blue	4918·2	2	
	4890·4	1	
	4877·4	3	
	4871·3	2	
	4870·5	2	
	4859·2	4	
	4788·6	5	
	4785·8	5	
	4709·4	5	
	4708·3	5	
	4706·5	5	
	4690·8	3	
	4653·4	3	
	4632·0	3	
	4610·6	3	
	4602·6	4	
	4591·9	3	
Indigo	4528·0	3	
	4414·7	1	very strong

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Indigo (*cont.*)	4404·2	1	very strong
	4382·8	1	
	4343·1	3	
	4325·2	1	strong
	4314·6	3	
	4307·2	1	G; strong
	4298·5	4	
	4293·9	4	
	4286·0	4	
	4271·3	1	
	4260·0	2	
	4250·5	1	
	4249·8	1	
	4247·5	4	
Violet	4235·5	3	
	4233·0	3	
	4226·8	5	
	4221·7	5	
	4218·3	5	
	4209·9	5	
	4201·5	2	
	4198·0	1	
	4191·2	2	
	4187·2	1	
	4186·7	1	
	4181·3	4	
	4177·0	4	
	4153·8	3	
	4151·5	4	
	4148·6	4	
	4143·1	1	
	4133·9	2	
	4131·5	1	
	4117·8	2	
	4071·0	1	
	4062·9	1	
	4045·0	1	
	4004·7	3	

Manganese (Mn).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6020·7	1	
	6015·6	1	
	6012·5	1	
Yellow	5515·6	5	
	5443·0	5	
	5419·5	3	
	5412·4	3	
	5406·5	5	
	5399·6	4	
	5393·5	4	
	5376·6	3	
	5359·0	4	
Green	5340·2	3	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Green (*cont.*)	5254·1	4	
	5233·6	4	
	5195·2	4	
Blue	4822·8	1	
	4782·6	1	
	4765·8	5	
	4764·7	1	
	4761·5	1	
	4760·7	5	
	4753·4	1	
	4738·0	3	
	4729·0	3	
	4726·0	3	
	4708·7	3	
Indigo	4503·5	5	
	4501·2	2	
	4498·2	2	
	4495·2	5	
	4491·0	5	
	4489·5	3	
	4478·9	5	
	4472·4	2	
	4470·5	2	
	4464·0	3	
	4461·5	3	
	4461·0	3	
	4459·8	5	
	4457·7	3	
	4457·3	4	
	4457·0	5	
	4456·2	5	
	4455·5	4	
	4455·2	3	
	4452·0	5	
	4450·4	3	
	4436·4	3	
	4435·3	5	
	4414·7	2	
	4280·5	3	
	4265·0	3	
	4258·2	3	
Violet	4234·8	1	
	4227·0	1	
	4083·5	3	
	4083·0	5	
	4079·6	3	
	4062·9	5	
	4054·4	3	
	4048·1	3	
	4040·5	3	
	4033·9	5	
	4032·8	5	
	4031·7	3	
Violet (*cont.*)	4029·4	2	
	3988·0	5	

Chromium (Cr).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Yellow	5409·0	2	
Green	5342·5	5	
	5341·0	5	
	5318·0	5	
	5313·0	5	
	5296·6	5	
	5296·1	5	
	5274·3	4	
	5263·4	4	
	5254·1	4	
	5246·3	4	
	5207·6	1	
	5205·2	1	
	5203·7	1	
	4924·0	4	
Blue	4653·9	4	
	4646·4	4	
Indigo	4495·2	4	
	4381·8	4	
	4369·2	4	
	4359·1	4	
	4351·8	2	
	4344·4	2	
	4338·2	2	
	4337·5	2	
	4336·8	3	
	4289·4	1	
	4274·6	1	
	4253·9	1	

Cobalt (Co).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6142·5	3	
	6121·2	3	
	6003·5	2	broad
Yellow	5482·4	4	
	5452·0	3	
	5443·0	3	
	5368·0	3	
	5362·5	5	
	5359·5	5	
	5352·4	3	
	5351·2	3	
Green	5342·6	5	
	5342·1	5	
	5279·6	3	double
	5267·2	5	
	5265·8	3	double
	5234·4	5	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Green (*cont.*)	5230.0	5	
	5212.0	5	
Blue	4867.0	1	
	4839.0	1	
	4813.5	1	
	4791.7	1	
	4778.7	1	
	4748.5	4	
	4580.8	4	
Indigo	4530.5	4	

Nickel (Ni).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6175.7	3	broad
	6115.3	4	
	6107.5	4	
	5892.0	1	
	5856.5	4	
Yellow	5475.9	3	
Green	5175.6	5	
	5168.3	5	
	5155.1	5	
	5145.7	5	
	5142.0	5	
	5136.8	5	
	5114.9	5	
	5099.7	5	
	5098.5	5	
	5080.6	5	
	5079.7	5	
	5034.6	3	
	5016.5	3	
	4983.3	5	
	4979.6	5	
	4935.1	3	
Blue	4917.6	3	
	4903.9	3	
	4872.9	1	
	4865.3	1	
	4854.7	1	
	4830.2	5	
	4828.4	5	
	4785.8	2	
	4755.0	5	
	4713.7	1	
	4647.0	5	
Indigo	4401.7	5	

Zinc (Zn).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6362.5	1	
	6102.0	1	broad
	6022.5	2	
	5893.5	2	
Yellow	5816.0	4	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Yellow (*cont.*)	5756.0	5	
	5745.0	5	
	5608.0	4	
	5577.5	4	
	5563.0	4	
	5465.5	4	
	5436.0	5	
Green	5336.0	5	
	5249.5	4	
	5233.0	4	
	5158.5	4	
	5121.0	4	
	5074.0	4	
	5048.0	4	
	4971.0	4	
	4923.8	1	very broad
Blue	4911.2	1	and diffused
	4878.0	5	
	4865.0	5	
	4809.7	1	
	4721.4	1	
	4679.5	1	

Cadmium (Cd).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6466.0	3	broad
	6438.0	1	
	6056.5	5	
	6003.5	5	
	5957.5	5	
	5913.0	5	
Yellow	5790.0	5	
	5687.0	4	diffused
	5489.0	5	
	5471.0	4	
	5378.0	1	very broad
Green	5337.5	1	and diffused
	5304.5	5	
	5153.0	4	
	5085.0	1	
Blue	4799.0	1	
	4676.8	1	
Indigo	4415.5	2	

Lead (Pb).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Red	6656.0	1	
Orange	6452.0	3	
	6059.0	5	
	6040.0	3	broad
	6009.0	5	
	6001.5	3	broad
	5895.0	5	
	5874.0	3	broad
	5856.5	4	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Yellow	5779·0	5	
	5607·0	1	broad
	5546·0	2	
	5523·5	4	
	5372·0	1	broad
Green	5274·5	5	
	5206·5	5	
	5201·0	3	
	5189·0	5	
	5163·0	4	
	5045·0	2	broad
	5004·5	3	
Blue	4802·0	5	diffused
	4796·5	5	
	4760·0	4	broad
	4573·0	5	
Indigo	4401·5	5	
	4386·5	1	broad
	4246·0	1	
Violet	4167·5	3	
	4062·5	4	
	4058·0	4	

Thallium (Tl).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	5947·5	3	
Yellow	5608·0	5	
	5490·0	5	
	5412·5	4	diffused
	5360·0	4	
	5349·5	1	broad
Green	5152·5	2	diffused
	5085·0	4	
	5078·5	3	diffused
	5053·0	3	
	4981·5	3	diffused
	4945·5	4	
Blue	4892·0	4	
	4735·5	3	broad

Bismuth (Bi).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Red	6599·0	4	
	6492·5	3	
Orange	6129·0	2	
	6056·5	2	
	6050·0	4	
	6038·5	4	
	5861·5	2	
Yellow	5816·0	3	
	5716·5	2	
	5655·0	4	
	5553·0	4	
	5450·0	2	broad
	5396·5	4	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Green	5270·0	2	broad
	5208·0	1	
	5201·0	4	diffused
	5143·5	1	broad
	5123·5	1	
	5090·0	5	diffused
	5077·5	4	
	4993·0	1	
	4970·0	5	
Blue	4905·0	4	
	4796·5	4	
	4752·5	5	
	4730·0	5	
	4722·0	1	
	4705·0	5	
	4691·5	4	
	4560·0	2	
Indigo	4339·5	4	
	4327·5	4	
	4302·0	3	
	4259·5	2	broad
Violet	4119·0	4	
	4084·5	5	

Copper (Cu).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6379·7	2	
	6218·3	5	
Yellow	5781·3	2	
	5700·4	1	
Green	5292·0	2	
	5217·1	1	
	5152·6	1	
	5104·9	1	
	5011·4	4	
	4955·5	3	
	4932·5	3	diffused
Blue	4911·5	3	
	4703·0	3	
	4650·7	3	
Indigo	4275·0	3	

Mercury (Hg).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6151·0	1	
	5888·0	2	
	5871·0	4	
Yellow	5789·5	1	
	5768·0	1	
	5678·0	2	
	5595·0	3	
	5460·5	1	broad
	5426·0	2	
	5364·5	4	diffused
Green	5278·5	5	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Green	5217·0	5	
(*cont.*)	5206·0	4	diffused
	5131·0	4	
	4958·0	3	
Blue	4916·0	4	
Indigo	4358·0	1	broad
Violet	4078·5	3	
	4047·0	3	
	3982·0	4	
	Silver (Ag).		
Orange	6036·0	5	
Yellow	5656·0	4	
	5645·0	4	diffused
	5625·5	4	
	5622·5	2	broad
	5610·5	4	
	5590·0	4	
	5568·0	4	diffused
	5556·5	5	
	5551·5	2	
	5522·0	4	diffused
	5486·5	5	
	5470·0	2	
	5464·0	1	
	5423·5	3	diffused
	5411·0	5	
	5401·5	2	broad
Green	5299·0	3	
	5208·7	1	
Blue	4874·0	2	
	4666·5	4	
Indigo	4475·0	4	
	Gold (Au).		
Orange	6276·5	2	
	5960·0	3	
	5955·0	3	
Yellow	5836·0	1	
Green	5230·0	1	
Blue	4792·0	3	
	Tin (Sn).		
Orange	6452·0	1	broad
Yellow	5798·0	1	
	5630·0	2	
	5588·5	1	broad
	5562·5	1	
	5368·5	5	
	5347·5	4	
Green	5332·0	2	broad
	5289·5	5	
	5224·0	4	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Green	5100·5	3	
(*cont.*)	5021·0	5	
	4923·0	4	
Blue	4858·0	3	
	4584·5	2	
Indigo	4524·0	1	broad
	Platinum (Pt).		
Red	6522·0	3	
Orange	5963·5	3	
Yellow	5845·0	4	
	5837·0	4	
	5806·0	4	
	5478·0	4	
	5475·5	4	
	5389·5	3	
	5367·5	2	
	5301·5	1	
	5226·0	2	
	5198·0	4	
	5059·5	2	
Blue	4879·0	4	
	4851·5	4	
	4803·0	4	
Indigo	4551·8	2	broad
	4498·2	2	
	4442·0	4	
	4389·4	4	
	4327·0	4	
	Palladium (Pd).		
Orange	6129·0	5	
Yellow	5694·0	3	
	5668·0	3	
	5651·0	4	
	5640·0	4	
	5618·0	3	
	5546·0	3	
	5542·0	3	
	5394·0	2	
	5361·5	4	
Green	5345·0	4	
	5312·0	4	
	5295·0	1	
	5257·0	4	
	5233·5	2	
	5208·0	4	
	5163·0	1	
	5116·5	2	
	5110·0	2	
Blue	4874·5	3	
	4817·0	3	
	4787·0	3	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Indigo	4473·5	3	
	4278·0	5	broad
Violet	4212·5	2	

Cerium (Ce).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Yellow	5654·0	5	
	5600·0	5	
	5564·0	5	
	5511·0	2	
	5472·0	3	
	5467·0	4	
	5463·0	5	
	5408·5	2	
	5392·5	2	
	5352·0	1	
Green	5330·0	3	
	5273·0	1	
	5190·5	4	
	5187·0	3	
	5161·0	5	
	5079·0	3	
	5072·0	4	
	4970·0	5	
Blue	4713·5	2	broad
	4628·0	1	
	4624·0	5	
	4605·5	5	
	4594·0	3	
	4582·5	5	
	4578·5	5	
	4572·5	1	
	4564·5	5	
	4562·0	1	
	4560·5	2	broad
Indigo	4539·5	2	
	4527·5	2	broad
	4526·5	1	
	4523·0	2	
	4486·0	5	
	4482·5	5	
	4479·0	5	
	4471·5	2	broad
	4467·0	5	
	4462·5	5	
	4459·5	1	broad
	4448·5	3	
	4443·5	3	
	4428·0	2	
	4419·0	2	
	4410·0	5	
	4398·5	5	
	4391·5	2	
	4385·5	2	
Indigo (*cont.*)	4382·0	2	
	4365·0	5	
	4296·0	1	
	4289·0	1	
Indigo	4185·5	3	broad
	4165·0	4	
	4149·0	4	
	4136·5	4	
	4132·5	4	
	4127·0	5	
	4124·0	5	

Didymium and Lanthanum (Di, La).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6346·0	5	Di
	6292·5	5	Di and La
	5973·5	5	
	5963·5	5	
Yellow	5805·5	5	
	5797·0	5	
	5790·0	4	
	5768·0	5	
	5500·0	3	
	5454·0	2	
	5381·0	3	
	5376·5	3	
Green	5339·0	4	
	5337·5	3	
	5303·0	2	broad Di and La
	5270·0	4	
	5257·5	5	
	5252·0	4	Di
	5233·5	4	
	5225·5	5	
	5211·0	4	
	5203·5	4	
	5187·5	1	
	5182·0	1	
	5177·0	4	
	5157·0	4	
	5144·0	4	
	5130·5	3	Di
	5122·5	3	
	5114·0	3	
	5055·5	5	
	4999·5	4	
	4968·0	4	
	4950·0	4	
	4934·0	4	
	4920·0	1	
Blue	4900·0*	1	Di and La
	4882·5*	1	

* See Erbium and Yttrium.

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Blue (*cont.*)	4860·0	4	Di and La
	4857·5	4	
	4823·0	4	
	4811·0	4	
	4802·0	4	
	4747·0	3	
	4741·5	3	
	4739·0	5	
	4702·5	3	
	4691·0	1	
	4671·0	2	
	4668·0	2	
	4663·5	1	
	4661·0	2	broad
	4654·5	1	
	4619·5	1	
	4613·5	2	
	4559·0	2	broad
Indigo	4525·0	2	
	4521·5	1	Di and La
	4430·0	1	broad, Di and La
	4354·5	4	
	4335·0	1	
	4295·5	2	broad, Di and La
	4287·5	2	Di and La
	4268·0	2	
	4262·5	1	
Violet	4237·0	1	
	4217·0	4	
	4196·0	4	
	4192·5	4	
	4141·5	4	
	4123·5	4	
	Uranium (U).		
Orange	5913·0	2	
Yellow	5619·0	3	
	5579·0	3	
	5562·5	3	
	5527·0	1	
	5509·0	3	
	5493·5	1	
	5481·5	1	
	5479·5	1	
	5477·0	1	
	5474·5	1	
	5384·0	3	
Green	5027·0	3	
Blue	4731·0	3	
	4723·0	3	
Indigo	4543·0	2	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Indigo (*cont.*)	4472·5	1	
	4393·5	3	
	4374·0	3	
	4362·0	3	
	4340·5	1	
	Titanium (Ti).		
Red	6555·7	4	
	6542·8	5	
Orange	6260·2	2	
	6257·4	1	broad
	6220·9	3	
	6214·1	3	
	6125·2	2	
	6097·4	3	
	6090·4	2	
	6083·2	3	
	6064·5	2	
	5998·7	2	
	5978·0	1	
	5965·3	1	
	5951·8	1	
	5921·5	3	
	5918·9	3	
	5899·0	1	
	5865·3	1	
Yellow	5738·0	3	
	5714·0	4	
	5701·5	5	diffused
	5688·5	2	
	5679·0	3	
	5674·4	1	
	5661·5	1	
	5647·0	4	
	5643·0	1	
	5629·0	5	diffused
	5597·2	5	
	5564·6	3	
	5513·4	1	
	5511·8	1	
	5502·8	2	
	5488·9	2	
	5486·8	3	
	5480·2	2	
	5476·5	3	
	5473·3	3	
	5470·5	4	
	5448·0	3	
	5445·8	4	
	5428·6	2	
	5425·0	3	
	5417·9	4	
	5408·6	2	

Colour of the Lines.	Wave-lengths.	Intensity	Remarks.
Yellow (*cont.*)	5403·1	3	
	5396·1	2	
	5380·2	3	broad
	5368·8	2	
	5350·5	2	
Green	5336·8	1	
	5298·5	3	
	5296·7	1	
	5295·5	3	
	5287·8	4	
	5282·8	1	
	5271·5	4	
	5267·2	4	
	5265·0	2	
	5262·9	4	
	5259·6	4	
	5255·0	4	
	5251·0	4	
	5246·3	2	broad
	5238·5	2	
	5226·0	3	*
	5223·0	1	broad
	5217·5	4	
	5209·5	1	broad
	5205·5	3	
	5200·5	3	
	5192·3	1	
	5188·3	2	
	5185·1	3	
	5173·0	2	
	5153·2	3	
	5151·2	2	
	5147·0	3	
	5144·5	2	
	5128·6	1	
	5126·6	4	
	5119·9	1	
	5113·0	2	
	5108·6	4	
	5102·4	4	
	5086·5	2	broad
	5076·5	4	
	5071·8	4	
	5065·5	4	
	5064·4	1	
	5061·3	3	
	5052·3	3	
Green (*cont.*)	5043·4	3	
	5039·2	2	
	5038·0	2	
	5035·6	1	
	5024·8	3	
	5023·8	3	
	5021·2	3	
	5019·4	2	
	5015·3	2	
	5013·3	1	
	5012·2	4	
	5006·6	1	
	5001·0	4	
	4998·8	1	
	4990·3	1	
	4988·3	3	
	4981·0	1	
	4977·8	3	
	4975·2	4	
	4972·2	5	
	4967·7	5	
	4964·5	5	
	4947·0	5	
	4937·2	2	
	4927·5	2	
	4925·0	4	
	4920·8	3	
	4919·0	3	
Blue	4913·2	3	
	4911·3	3	
	4903·9	4	
	4899·3	2	
	4884·5	1	
	4873·0	4	
	4869·0	2	
	4867·5	2	
	4855·0	2	
	4848·0	3	
	4840·0	2	
	4835·0	4	
	4819·5	2	broad
	4804·3	1	
	4797·5	4	
	4791·6	2	
	4779·0	3	
	4758·5	1	
	4757·0	1	

* The corresponding line in the Solar Spectrum, which usually appears as a single very strong line, is separated by greater dispersive power into three distinct lines, the strongest of which belongs to iron, and one of the others to titanium.

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Blue (*cont.*)	4741·8	2	
	4722·8	2	
	4709·0	2	
	4698·0	2	
	4690·6	2	
	4681·5	2	
	4666·5	2	
	4656·0	1	broad
	4644·0	4	
	4638·8	1	broad
	4629·0	3	
	4623·0	2	
	4616·7	2	
	4571·5	1	broad
	4563·2	2	
	4555·3	3	
Indigo	4551·8	3	
	4548·9	1	broad
	4543·5	3	
	4535·5 } 4532·0 }	1	very broad
	4526·1	1	
	4521·9	3	
	4517·5	3	
	4511·5	3	
	4500·7	1	} broad
	4496·1	2	} broad
	4481·0	3	} broad
	4468·5	1	} broad
	4457·5	2	
	4455·0	2	
	4452·5	2	
	4449·5	2	
	4446·5	2	
	4443·0	1	} broad
	4426·8	1	} broad
	4417·8	2	} broad
	4411·0	3	
	4403·0	3	
	4398·5	3	
	4393·0	1	broad
	4337·5	1	
	4323·5	2	broad
	4320·0	5	
	4318·0	5	
	4313·5	5	
	4312·5	5	
	4307·5	5	
	4305·0	2	
	4299·0	1	broad
	4295·0	5	
	4293·8	5	
	4290·7	2	broad

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Indigo (*cont.*)	4287·0	5	
	4282·0	5	
	4273·0	5	
	4263·0	2	
Violet	4236·5	2	
	4185·0	3	
	4171·0	1	} broad
	4163·0	1	} broad

Wolfram (W).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Yellow	5805·0	4	
	5733·0	3	
	5648·0	4	
	5631·5	5	
	5513·0	1	
	5491·5	2	
Green	5223·0	1	
	5070·5	3	
	5008·0	3	
	5053·0	1	
	5014·0	3	
	5007·0	3	
	4981·0	4	
Blue	4887·5	2	
	4842·0	1	
	4680·5	5	
	4660·5	5	
	4659·5	5	
Indigo	4302·0	3	
	4295·0	3	
	4269·0	3	

Molybdenum (Mo).

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Orange	6029·0	1	
	5887·5	1	
	5856·5	2	
Yellow	5791·0	3	
	5750·0	3	
	5687·5	3	
	5649·0	4	
	5631·0	4	
	5569·0	1	
	5540·0	5	
	5531·5	1	
	5505·0	1	
	5360·0	4	broad
Green	4979·0	5	
Blue	4867·5	4	broad
	4829·5	4	
	4818·0	4	
	4757·5	4	
	4730·5	4	
	4706·5	4	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Indigo	4536·0	4	
	4475·0	4	
	4433·5	4	
	4411·5	4	
	4380·5	4	
	4326·0	4	
	4277·5	3	broad
	Vanadium (V).		
Orange	6240·5	3	
	6134·4	4	
	6119·0	1	
	6109·5	4	
	6089·0	1	
	6080·0	4	
	6039·0	1	
Yellow	5786·0	4	
	5725·0	1	
	5706·0	4	
	5702·5	3	
	5697·5	2	
	5668·0	3	
	5626·0	3	
	5622·5	3	
	5414·0	3	
	5401·0	4	
Green	5240·0	3	
	5233·0	3	
	5195·0	4	
	5191·5	4	
Blue	4881·0	3	
	4874·5	3	
	4864·0	4	
	4851·0	5	
	4843·0	3	broad
	4831·5	5	
	4593·0	3	
	4585·0	4	
	4579·0	5	
	4576·0	5	
Indigo	4459·0	2	broad
	4407·5	1	
	4406·0	4	
	4400·5	5	
	4395·0	3	
	4389·0	2	
	4384·0	1	
	4379·0	1	broad
	4352·5	5	
	4340·5	5	
	4332·5	5	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Violet (*cont.*)	4329·5	5	
	4310·0	5	
	4297·0	4	
	4292·5	5	
	4283·5	5	
	4277·0	5	
	4272·0	4	
	4268·5	4	
Violet	4110·0	3*	
	Osmium (Os).		
Indigo	4422·0	4	
	Antimony (Sb).		
Orange	6301·5	2	
	6244·5	4	
	6209·0	4	
	6193·0	4	
	6155·0	4	
	6128·5	1	
	6078·0	1	
	6051·0	4	
	6003·5	1	
	5979·5	4	
	5909·0	2	broad
	5893·5	2	
Yellow	5791·5	4	diffused
	5638·0	2	broad
	5607·0	5	
	5567·0	2	
	5463·5	3	broad
	5379·0	3	
	5371·5	5	
	5352·5	5	diffused
Green	5241·5	3	broad
	5208·0	5	
	5177·0	3	
	5141·0	4	diffused
	5112·5	4	
	5036·0	5	
	4948·5	2	broad
Blue	4877·5	3	
	4835·0	4	diffused
	4786·0	4	
	4734·5	4	
	4711·0	2	broad
	4691·0	3	
	4591·5	3	
Indigo	4352·0	2	broad
	4265·0	3	

* Several very faint lines lie between 4130 and 4085.

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
	Arsenic (As).		
Orange	6169·5	2	
	6110·0	2	broad
	6021·5	4	
Yellow	5651·0	2	
	5558·0	2	broad
	5498·0	3	
Green	5331·5	3	
	Tellurium (Te).		
Orange	6437·0	1	
	6046·0	3	
	6012·5	3	
	5973·0	1	
	5935·0	2	
	5856·5	4	
Yellow	5852·0	4	
	5825·0	4	diffused
	5805·5	4	
	5781·0	3	
	5755·0	1	
	5741·0	5	
	5706·5	1	
	5647·0	1	
	5616·0	4	
	5574·0	2	
	5488·0	3	
	5477·5	3	
	5447·5	2	
	5408·5	4	
	5366·0	3	
Green	5310·0	3	
	5299·0	5	
	5217·0	2	
	5172·0	5	
	5152·0	3	
	5133·0	5	diffused
	5104·5	3	
	5035·0	4	
Blue	4895·0	5	
	4866·5	4	diffused
	4832·0	5	
	4785·0	5	
	4603·5	4	
	Indium (In).		
Indigo	4531·5	3	very broad and diffused
	4509·5	1	
Violet	4101·0	1	broad

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
	Spectrum of the Air.		
Red	6602·0	3	
	6561·8	1	C; broad
	6479·5	3	
Orange	6170·5	3	broad
	5949·0	4	
	5941·5	1	broad
	5932·0	1	
	5929·5	4	
Yellow	5767·0	4	
	5745·0	4	
	5711·0	3	
	5685·5	3	
	5678·0	1	broad
	5674·5	3	
	5666·0	1	
	5549·0	4	
	5541·0	3	
	5534·0	1	
	5530·0	3	
	5495·0	2	
	5479·0	3	
	5461·5	4	
	5453·0	4	
	5351·0	5	
Green	5339·5	5	
	5320·0	5	
	5189·5	4	
	5184·5	5	
	5178·0	4	
	5172·0	5	
	5045·0	1	broad
	5025·0	2	
	5016·0	3	
	5010·0	3	
	5006·5	4	
	5005·0	1	broad
	5002·0	1	
	4993·5	3	
	4987·0	3	
	4941·0	4	
	4924·0	4	
Blue	4906·0	4	
	4895·5	4	
	4803·0	1	
	4788·0	1	
	4779·0	1	
	4712·0	4	
	4706·5	2	
	4698·0	2	
	4675·0	4	
	4661·5	4	
	4649·0	2	

Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.	Colour of the Lines.	Wave-lengths.	Intensity.	Remarks.
Blue (*cont.*)	4642·0	1		Indigo (*cont.*)	4333·0	3	broad and diffused
	4640·0	3			4319·0	2	
	4630·5	1	broad		4316·5	2	
	4621·0	2		Violet	4230·0	2	broad and diffused
	4613·0	2			4189·5	3	
	4606·5	2			4184·5	3	
	4601·0	2			4155·0	5	diffused
	4596·0	3			4149·0	5	
	4590·5	3			4137·0	4	broad and diffused
Indigo	4446·5	1	broad		4123·0	3	
	4432·0	3	broad and diffused		4075·5	3	
	4418·0	1			4074·0	3	diffused
	4414·5	1			4071·5	3	
	4368·0	4	diffused		4069·5	3	
	4350·5	3			4040·0	4	
	4347·5	1	broad		3995·0	4	
	4346·0	3					

APPENDIX J.

To page 158.

The following tables of the bright lines occurring in the spectra of the principal non-metallic elements give their wave-lengths in ten millionths of a millimetre. In their compilation we have to some extent been indebted to Watts' "Index of Spectra."

1. *Oxygen.*

Plücker.	Huggins.	Plücker.	Huggins.	Plücker.	Huggins.	Plücker.	Huggins.
6452		5144		4850	4853	4662	4662
6170		4954	4953	4848		4649	4648
6118		4941	4943	4754		4640	
5340		4925	4925	4744		4639	
5315		4900	4907	4711		4600	
	5205	4884	4892	4706	4705		4596
5190	5190	4866	4872	4698	4699	4593	
5178		4862		4690			4588
5161	5163	4856		4675	4677	4474	

Plücker.	Huggins.	Plücker.	Huggins.	Plücker.	Huggins.	Plücker.	Huggins.
4468	4467	4348		4262	4278	4117	4117
4457		4347		4243		4104	
4450		4341		4190	4190	4094	
4443		4334		4171	4183	4086	
4418	4416	4327		4158		4085	
4414	4414	4320		4147	4149	4072	4073
4398				4136		4069	4069
4367	4364	4317	4318	4126			

2. *Hydrogen.*

Hα . .	6562	Angström	Hγ . .	4340	Ångström
Hβ . .	4861	,,	Hδ . .	4101	,,

3. *Nitrogen.*

Plücker.	Huggins.	Plücker.	Huggins.	Plücker.	Huggins.
6602	6602	5453	5462	4630	4629
6480	6482	5341	5453	4621	4621
6376		5330	5350	4613	4613
6358		5309	5338	4609	4608
6341		5164	5319	4601	4600
6288		5160 Band	5179	4551 Band	4553
6249		5152	5176	4544	4533
6165 Band		5120	5172	4532	4506
6152		5098		4523 ,,	4496
5949	5950	5071	5071	4506	4490
5942	5942	5045	5045	4500 ,,	4477
5932	5930	5025	5024	4447	4448
5929	5925	5016	5016	4438	4432
5767	5768	5010	5010	4421 ,,	4422
5754	5746	5005	5007		4398
5711	5726	5002	5003	4247	4238
5686	5709	4992	4999	4227 ,,	
5681	5686	4986	4993	4214	4206
5676	5680		4986	4199 ,,	
5666	5675		4931	4184	
5560	5668	4894	4895	4170 ,,	4170
5549	5550	4876	4880	4151	4142
5541	5541	4859	4866	4147 ,,	
5530	5534	4846	4858	4141	4130
5524	5528	4804	4849	4130 ,,	4101
5495	5524	4743	4804	4097	4094
5479	5495	4732	4788	4080 ,,	4038
5462	5479	4644	4781		4000

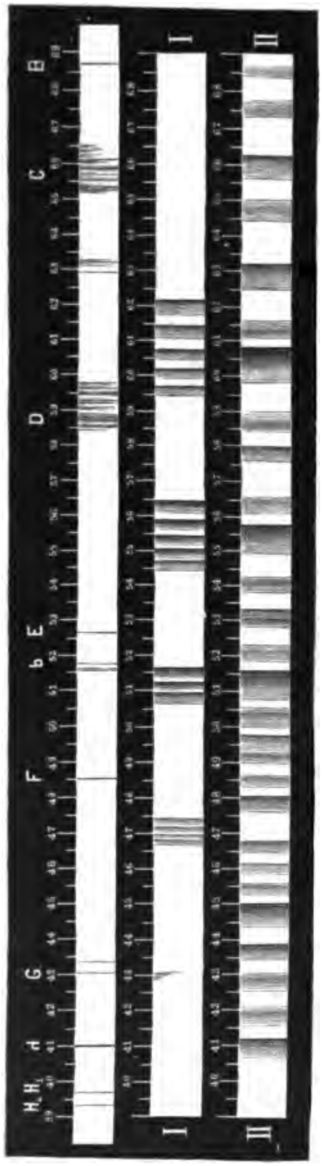

FIG. 291. - Spectrum of Carburetted Hydrogen (I); Spectrum of Carbonic Acid (II), after Ångström and Thalén.

The atmospheric air when dry yields the same spectrum as pure nitrogen.

4. *Carbon.*

As early as 1863 the spectrum of pure carbon was observed by Ångström and Thalén, and recognized by them as a spectrum of lines. They described it as follows:—With the red at the left of the observer, the spectrum consists of a very marked double line to the right of C, of several fine but sharply defined lines between D and E, of three prominent lines to the left of *b*, and finally of a band to the left of G. This band increases in breadth in proportion as the electric current gains in intensity, and its resemblance to the two bands of hydrogen at F and near to G is worthy of remark. Working with a weak solution of carbonic oxide, the band appears as an isolated line, but under ordinary circumstances as a broad band diffused at the edges. The red line has also been observed by Dr. Huggins. The following are the wave-lengths given for the carbon lines by Ångström and Thalén:

Colour of the Lines.	Wave-lengths.	Colour of the Lines.	Wave-lengths.
Red	6583·0 6577·5	Yellow . . .	5379·0
Orange	5694·1 5660·9 5646·5 5638·6	Green . . .	5150·5 5144·2 5133·0
		Indigo . . .	4266·0

The very complicated spectra of the various compounds of carbon have been the subject of many investigations both with the flame and the electric spark, but hitherto with no very certain results. It will be as well, however, to give here the wave-lengths in ten millionths of a millimetre of the bright lines of carburetted hydrogen as observed by Ångström and Thalén :—

First Group.	Second Group.	Third Group.	Fourth Group.
Orange 6187·3 6119·0 6056·3 6000·8 5953·5	Yellow 5633·0 5583·0 5538·0 5500·0 5466·0	Green 5164·0 5128·0 5097·5	Blue 4736·0 4714·0 4697·0 4682·0

Fifth Group. Indigo : 4311·0, broad.

Fig. 291 represents the spectrum of carburetted hydrogen, No. I., and that of carbonic acid, No. II., as observed by Ångström and Thalén ; above stands the solar spectrum with the Fraunhofer lines.

5. *Phosphorus.*

Phosphorus when vaporized in the electric spark gives the following lines as determined by Plücker :—

6505	6057	5540	5381	4600		4477	
6457	6043	5500	5358	4588		4477	Band
6433	6032	5486	5337	4562	Band	4468	
6370	5990	5480	5306	4554		4423	
6200	5964	5462	5284	4532	”	4232	
6173	5601	5452	5243	4526		4222	
6100	5589	5420	5178	4503	”	4180	
6071	5552	5402	4972	4499			

6. *Sulphur.*

Plücker gives the wave-lengths as follows :—

6579	5641	5218	5004	4723		4563	Band	4317	Band
6454	5618	5207	5003	4718		4560		4313	
6421	5609	5199	5000	4694	Band	4552		4297	
6404	5584	5191	4990	4690		4523		4284	
6390	5568	5182	4942	4677		4485		·4279	
6321	5558	5143	4924	4666	,,	4466		4272	
6309	5532	5141	4922	4661		4434	Band	4259	
6290	5522	5140	4902	4654	,,	4430		4255	
6152	5508	5124	4884	4632		4424	,,	4242	Band
6111	5473	5110	4825	4628	,,	4421		4240	
6009	5452	5096	4813	4613		4389	,,	4230	
5866	5438	5068	4804	4608	,,	4384		4227	,,
5810	5425	5044	4791	4596		4358		4198	
5780	5338	5036	4777	4590	,,	4350		4194	,,
5667	5304	5030	4768	4583		4343		4181	
5657	5269	5024	4762	4578	,,	4336		4168	
5650	5231	5013	4734			4329		4158	
								4140	

7. *Iodine.*

The lines have been measured by Plücker with the following results :—

6861	6131	5739	5499	5292	5047
6825	6087	5713	5494	5262	5028
6757	6073	5705	5482	5257	4990
6690	6067	5696	5468	5235	4972
6640	5956	5683	5460	5218	4960
6576	5920	5649	5441	5209	4946
6494	5889	5632	5422	5176	4922
6339	5886	5620	5402	5166	4886
6292	5866	5607	5377	5150	4853
6257	5821	5600	5365	5138	4838
6210	5790	5558	5339	5107	4832
6169	5777	5530	5330	5102	4809
6154	5763	5511	5314	5064	4636

8. *Bromine.*

The following are the lines observed by Plücker and Hittorf in the emission spectrum of bromium :—

6862	5792	5502	5250	5035	4807	4676
6628	5739	5492	5225	5010	4787	4644
6576	5722	5446	5220	4990	4778	4625
6555	5712	5436	5216	4982	4771	4543
6357	5696	5428	5187	4960	4746	4365
6158	5662	5422	5180	4945	4736	4288
6151	5626	5391	5168	4932	4730	4241
6131	5622	5383	5150	4924	4721	4228
6128	5598	5326	5122	4868	4706	4198
5868	5566	5299	5106	4852	4695	4181
5827	5552	5292	5092	4847	4680	4142
5824	5515	5263	5054	4818		

9. *Chlorine.*

The following lines have been measured by Plücker :—

6730	5601	5205	5006	4800	4615	
6692	5577	5180	5004	4790	4590	
6665	5540	5176	4998	4786	4579	Band
6645	5533	5161	4974	4782	4574	
6108	5460	5160	4948	4778	4346	
5952	5444	5150	4942	4777	4338	
5934	5422	5148	4930	4765	4310	
5788	5385	5101	4924	4749	4293	
5716	5346	5099	4907	4711	4280	
5685	5325	5077	4899	4650	4277	
5674	5274	5066	4825	4634	4258	
5640	5212	5044	4814			

APPENDIX K.

To page 200.

On the Relative Intensities of the Dark and Bright Lines.

The question may well be asked, Why, if the weak sodium flame absorb the yellow rays from the intense white light that passes through it, do not the yellow rays of the flame itself again replace the yellow sodium line? A somewhat closer investigation of all the influences at work will not only give materials for fully answering this inquiry, but afford the means also of clearly explaining the cause and true nature of the dark lines.

Let I designate the intensity of the *white* light of the incandescent solid or liquid body, taking the electric light as an example, *i* that of the absorptive flame, which for the sake of simplicity we will suppose to be a sodium flame, and $\frac{I}{n}$ the proportion between the absorptive and the emissive powers of this flame—that is to say, $\frac{I}{n}$ is lost by absorption from the total intensity. If then the white light I pass through the sodium flame, and suffer a loss in intensity by absorption of $\frac{I}{n}$, there will be in the place of the

spectrum where the sodium line appears, which we will call D, an amount of light equal to $I - \frac{I}{n} + i$. The amount of absorption $\frac{I}{n}$ diminishes the intensity of the spectrum at the spot D, but the intensity of the sodium flame will to a greater or less degree supply the deficiency. If the amount of the absorption were precisely equal to the intensity i, the intensity of the spectrum at the spot D would be just as great as that of the neighbouring parts and there would therefore be no interruption of the spectrum; there would neither be a dark line nor a bright line visible. If the intensity i of the sodium flame be greater than the absorption $\frac{I}{n}$ the brightness of the spot D in the spectrum would be greater than on either side of it, and there would appear at this place a bright yellow sodium line, although the white light had passed through the absorptive flame; the reverse will be the case if the intensity i of this flame be less than the whole absorption; the brightness of the spectrum at the spot D will then be less than that of the surrounding parts. In the last case, however, this want of light will appear as a shadow by contrast with the brightness of the neighbouring places, and the usual bright yellow sodium line will seem to be a dark line.

It will be seen further, from this investigation, that in the places where the dark absorption lines appear there is by no means a total absence of light; therefore these lines should not be described as quite black; but in contrast with the surrounding brilliancy produced by the full undiminished light of the incandescent solid or liquid body, these lines *appear* quite black even when their brightness exceeds that of the absorbing vapour.

The whole action of the *reversal* of a bright spectrum line into a dark one rests on the proportion between the absorptive power and the compensating emissive power in the absorbing vapour: the greater the absorptive power, and the less the emissive power, further, the greater the light of the incandescent body, so much the darker will the reversed lines appear to be.

The following table will serve to elucidate the foregoing remarks, by giving four examples for the sodium line :—

No.	The Intensity of the White Light is called	The Intensity of the Sodium Flame is	The Absorptive Power of the Sodium Vapour is	The Intensity of the Spectrum before the Sodium Line is then	The Intensity of the Spectrum in the Sodium Line is then	The Intensity of the Spectrum behind the Sodium Line is then	The Sodium Line appears therefore
1	2	1	$\frac{1}{4}$	2	$3 - \frac{2}{4} = 2\frac{1}{2}$	2	bright.
2	10	1	$\frac{1}{4}$	20	$11 - \frac{10}{4} = 8\frac{1}{2}$	10	dark.
3	100	1	$\frac{1}{2}$	100	$101 - \frac{100}{2} = 51$	100	darker.
4	100	1	$\frac{3}{4}$	100	$101 - \frac{300}{4} = 26$	100	very dark.

In the first case, the place D is $\frac{1}{2}$ brighter than the surrounding parts of the spectrum; therefore it appears as a *bright* sodium line; in No. 2, the brightness of the place D is only equal to $8\frac{1}{2}$, while that of either side is 10; it is therefore not so bright at D as at the side of D, and in consequence D appears dark against the surrounding parts of the spectrum. In No. 3, the contrast is still greater between the light at D 51 and that at the side 100. Finally, in No. 4, where the absorptive power of the flame is assumed to be $\frac{3}{4}$, the contrast between the strength of light, 100 and 26, is so great that the line seems almost black. The intensity with which the yellow line of sodium and the red line of lithium appear when these substances are heated in a Bunsen burner warrants the conclusion that these metals would also absorb with great power rays of the same refrangibility, and therefore the assumed absorptive power, $\frac{3}{4}$, given in the last example, is considerably below the truth.

APPENDIX L.

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LOCKYER'S TABLES OF THE COINCIDENCE OF THE FRAUNHOFER LINES WITH THE LINES OF METALS.

The various observers upon whose authority the coincidence of the lines is given are distinguished by the initial letter of their names: S=Stokes, K=Kirchhoff, A=Ångström, T=Thalén, L=Lockyer.

ELEMENTS WHOSE PRESENCE IN THE SUN'S REVERSING LAYER HAS BEEN CONFIRMED.

Name of Element.	Evidence.	Authority.
Sodium	Reversal of D-lines	S., K
Iron	Reversal of 450 lines	K.
Calcium	Reversal of 75 lines	K.
Magnesium	Reversal of 4 (3?) lines	K.
Chromium	Reversal of 18 lines	K.
Nickel	Reversal of 33 lines	K.
Barium	Reversal of 11 lines (of 26)	K.
Zinc	Reversal of 2? lines (of 27)	K.
Cobalt	Reversal of 19 lines	T.
Hydrogen	Reversal of 4 lines (all)	A.
Manganese	Reversal of 57 lines	A.
Titanium	Reversal of 118 lines	T.
Aluminium	Reversal of the two longest lines at wave-lengths 3943·30 and 3960·50	L.
Strontium	Reversal of 4 lines at wave-lengths 4029·6, 4076·77, 4215·00, and 4607·5	L.
Lead	Reversal of 3 lines at wave-lengths 4019·28, 4056·8, and 4061·25	L.
Cadmium	Reversal of 2 lines at wave-lengths 4677·0 and 4799·00	L.
Cerium	Reversal of 2 lines at wave-lengths 3928·7 and 4012·0	L.
Uranium	Reversal of 3 lines at wave-lengths 3931·0, 3943·0, and 3965·8	L.
Potassium	Reversal of 2 lines at wave-lengths 4042·75 and 4046·28 (apparently the only K-lines in this region of the spectrum)	L.
Vanadium	Reversal of 4 lines at wave-lengths 4379·0, 4384·0, 4389·0, and 4407·5	L.
Palladium	Reversal of 5 lines at wave-lengths 3893·0, 3958·0, 4787·0, 4817·0, and 4874·0	L.
Molybdenum	Reversal of 4 lines at wave-lengths 3902·0, 4576·0, 4706·0, and 4730·0	L.

Elements whose Presence in the Sun's Reversing Layer is Probable.

Name of Element.	Reason of Doubt.	Authority.
Indium . .	One line at wave-length 4101·0 is apparently coincident with *h*, hitherto regarded as a hydrogen line. The reversal of another line at wave-length 4509·0 is doubtful	L.
Lithium . .	One line at wave-length 4603·0 is reversed, but the reversal of the long red line at wave-length 6705 has not yet been detected	L.
Rubidium .	One long line at wave-length 4202·0 is reversed, but solar lines corresponding to the long red lines at wave-lengths 6205 and 6296 have hitherto escaped detection	L.
Cæsium . .	Two lines at wave-lengths 4554·9 and 4592 are possibly reversed, but a better photograph is needed to settle the question	L.
Bismuth . .	One line at wave-length 4722·0 is reversed, but further evidence considered necessary	L.
Tin . . .	One line at wave-length 4524 is apparently reversed, but further evidence is desirable	L.
Silver . .	Two lines at wave-lengths 4018·0 and 4212·0, which are reversed in the metallic spectrum, are of very great width, and I have not yet had time to determine whether they are coincident or not with lines in the solar spectrum, by alloying silver with copper, or some other metal, so as to thin down the lines	L.
Glucinum .	One line at wave-length 3904·77 is apparently reversed, but further evidence desirable	L.
Lanthanum .	Three winged lines at wave-lengths 3948·20, 3988·0, and 3995·04 are reversed	L.
Yttrium, or Erbium	Two lines at wave-lengths 3981·87 and 3949·55 are reversed	L.

Elements Absent from Sun's Reversing Layer, so far as our Knowledge at Present Extends.

Name of Element.	Evidence.	Authority.
Carbon * .	No coincidences with the carbon lines	A.
Silicium . .	No reversals determined	K.
Thallium .	The long green line at wave-length 5349 is apparently not reversed	L.
Chlorine, Bromine, Iodine	No coincidence observed between solar lines and the bright lines seen in the jar-spark spectrum	L.

* [Mr. Lockyer has found Carbon.]

ERRATA.

Page 87, line 2 of note, *for* collimata *read* collimator.
" 216, line 1 of note, *for* Fig. 109 *read* Fig. 108.
" 358, line 21, *for* (Fig. 195) *read* (Fig. 162).
" 441, line 17, the bracket should be after "1591

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